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EFFORTS ON MARINE DEBRIS IN THE OCEANS AND GREAT LAKES

HEARING

BEFORE THE

SUBCOMMITTEE ON OCEANS, ATMOSPHERE, FISHERIES, AND COAST GUARD

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED FIFTEENTH CONGRESS

FIRST SESSION

JULY 25, 2017

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

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EFFORTS ON MARINE DEBRIS IN THE OCEANS AND GREAT LAKES

TUESDAY, JULY 25, 2017

U.S. SENATE,
SUBCOMMITTEE ON OCEANS, ATMOSPHERE, FISHERIES, AND COAST GUARD,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 10:03 a.m. in room SR–253, Russell Senate Office Building, Hon. Dan Sullivan, Chairman of the Subcommittee, presiding.

Present: Senators Sullivan [presiding], Fischer, Inhofe, Gardner, Young, Peters, Cantwell, Blumenthal, Schatz, Markey, and Booker.

OPENING STATEMENT OF HON. DAN SULLIVAN, U.S. SENATOR FROM ALASKA

Senator SULLIVAN. The Subcommittee on Oceans, Atmosphere, Fisheries, and the Coast Guard will now come to order.

Good morning, everybody. I'd like to thank our witnesses for appearing. We have two panels today of very distinguished witnesses.

I also just want to mention at the outset that this is one of these issues I think a lot of times takes place in Washington, but you don't get a lot of media attention because they are very bipartisan, and sometimes I think our media, whether here or back home, loves to focus on the conflict. But on a big issue that's very important to the country that's bipartisan, you get a little less attention maybe because there's not so much conflict here.

But, nevertheless, I want to thank my colleagues for being here. I particularly want to thank Senator Booker for his leadership on this issue. Hopefully, Senator Whitehouse is going to be joining us soon.

But as all of you know, marine debris poses a significant threat to our natural areas, wildlife, shorelines across the United States, our fisheries, but also across the globe. Eight million metric tons of marine debris enters our oceans and Great Lakes every year. My state of Alaska, in particular, is impacted. We have 34,000 miles of coastline, larger than any other state, and as a matter of fact, larger than the rest of the coastline of the United States combined, and we are very negatively impacted by marine debris as ocean currents carry millions of tons of trash to our shores in Alaska.

But it's not just marine debris impacting the livelihood of the people of my state. It's literally every state with a shoreline, whether New Jersey or Hawaii or Michigan, in our country. What is particularly troubling about the marine debris challenge and crisis—

and we believe it's absolutely a crisis—is that the majority of marine debris in the world's oceans come from five countries in Asia—China, Thailand, the Philippines, Vietnam, Indonesia, and South Korea.

So a few months ago, a bipartisan group of my Senate colleagues and I introduced the Save Our Seas Act, which takes steps to engage these countries, which is why it's so important to have the State Department represented here, and also provide our Federal agencies with the resources they need to clean up our waters and prevent trash from becoming marine debris.

It's encouraging that Senators from both sides of the aisle are working together to introduce meaningful legislation to tackle the important issue of marine debris, and our bill has already been unanimously moved out of the Commerce Committee, and I believe we're starting to look at the possibility of hot-lining it. The Save Our Seas Act encourages the administration and State Department to engage with the world's leading trash producers and to take steps to address the impact of marine debris so that we can, together, become better stewards of our environment, oceans, and waterways.

Not only should we be helping other countries both with their waste management infrastructure, but we should also try to help facilitate the cultural change. As children in this country, we learn about recycling and are taught about respect for our environment and natural places, but this is not the case everywhere in the world, and I look forward to hearing from Ambassador Balton how we can help export this stewardship mentality to other nations.

The Save Our Seas Act also reauthorizes NOAA's important Marine Debris Program, which is led by Ms. Wallace, our other witness today. It has helped to clean debris on America's shorelines and the Great Lakes since 2006. The Save Our Seas Act would also provide additional support to states in the event of severe marine debris events like the one we saw following the Fukushima tsunami.

Last Congress, I had the opportunity to hold a hearing on this topic as Chairman of the Senate Environment and Public Works Committee's Subcommittee on Fisheries, Water, and Wildlife. And, again, I want to thank Senator Whitehouse for his leadership on that committee. Last year, he and I were the Chair and Ranking Member on that hearing, and I look forward today to building on that, to hear the perspective of Federal agencies and others most engaged on this topic, and to learn about their efforts to combat marine debris and suggestions on how we in the Congress can do a better job.

Our oceans are a bipartisan issue. Please accept the introduction and unanimous support of this committee of the Save Our Seas Act as a demonstration of that bipartisan support. I want to thank our witnesses, Senator Peters, and others for the hard work on this important legislation. We are looking forward to a meaningful committee hearing today.

Senator Peters.

STATEMENT OF HON. GARY PETERS, U.S. SENATOR FROM MICHIGAN

Senator PETERS. Well, thank you, Chairman Sullivan, for calling this hearing, and I want to also join in thanking our witnesses, Ambassador Balton, Director Wallace, and I'm pleased to welcome Dr. Melissa Duhaime from the University of Michigan, who will be sharing her research and expertise on debris in the Great Lakes.

Mr. Chairman, clearly, your state, with the longest shoreline in the United States, is vulnerable to the negative consequences of marine debris. But my home state of Michigan certainly is not immune from it, with more freshwater coastline than any other state and second only to Alaska in total shoreline. And though we may call it marine debris, what we're really talking about is trash pollution in our water, water that is in the Great Lakes providing drinking water, navigation, abundant opportunities for recreation, including fishing, boating, and diving.

Folks used to think that dilution is the solution to pollution, but in the Great Lakes, the negative consequences of that strategy are readily apparent. In 2015 alone, the Alliance for the Great Lakes removed nearly 100,000 pounds of debris from Great Lakes coastal habitats, and that didn't even put a dent in it because scientists estimate that there are nearly 22 million pounds of plastic pollution that enter into the Great Lakes every single year. In Lake Michigan alone, that translates to approximately 100 Olympic size pools full of plastic bottles every year going into it.

While surface currents move ocean debris into floating garbage patches, winds and lake currents often bring Great Lakes trash right onto our beautiful beaches. So it's no surprise that in 1970, it was a Great Lakes senator, Gaylord Nelson, who spearheaded the very first Earth Day. Around that time, the three R's emerged, and school children were learning to recycle, reduce, and reuse. And to this day, the three R's provide a roadmap to address our growing trash problem, both in the Great Lakes as well as in the oceans.

And, yes, cleanup is certainly essential, but we have to stem the tide of trash before it actually enters into the waterways. In Michigan, NOAA is playing a very key role. The Northeast Michigan Great Lakes Stewardship Initiative, Michigan Sea Grant, Michigan State University Extension Office, and the Thunder Bay National Marine Sanctuary have come together in a partnership with schools, teachers, and, most importantly, with leaders of tomorrow to raise awareness about Great Lakes trash pollution.

Last year, a team of Alpena, Michigan, public school students at Ella M. White Elementary School used nets to trawl for garbage in the Thunder Bay River, and they were shocked with what they found. So they created a film called Plastics 101, and the video adds a fourth R to the old adage, and that is refuse, meaning to refuse single use plastics whenever you can. So I think it's safe to say that their families are probably now using reusable grocery bags and water bottles after the production of that film, and this creative and informative film will be shown to third, fourth, and fifth graders learning about single use plastic pollution.

Trash pollution is also a global problem in need of global solutions. The U.S. is a party to both the international treaties governing at sea waste disposal, the London Convention and MARPOL Annex V. But as I believe you will hear today, most marine debris, about 80 percent, actually starts on land. It isn't intentionally released into our water, but it ends up there because of waste management—can certainly be a challenge—or due to natural processes like wind, storms, or floods. The Department of State is integral to efforts to improve waste management systems in developing nations.

So, Mr. Chairman, I'm heartened by your leadership on the Save Our Seas Act and your eagerness to work together to strengthen the marine debris program at NOAA and the Department of State. I'm concerned that if we don't adequately fund these initiatives, we will pay for it in the long run. Trash pollution impedes waterborne commerce, it can introduce invasive species that wreak havoc on local ecosystems as well as our economies, and trash pollution introduces chemicals into our food chain.

But this problem is one that we can begin to address, and I'm confident that our up and coming leaders, folks like the Ella White Elementary River Raiders and Bob Thompson's class will use technology, innovation, and awareness much better than we may have done in the past. But one thing is for sure. They are certainly watching our example here today, and we look forward to making a move forward.

Thank you.

Senator SULLIVAN. Thank you, Senator Peters.

I appreciate the witnesses that we have for this hearing today: Ambassador David Balton, the Deputy Assistant Secretary for Oceans, Fisheries, and the Bureau of Oceans and International Environment and Scientific Affairs; and Nancy Wallace, the Director of NOAA's Marine Debris Program.

You will have five minutes to deliver your oral statement. A longer written statement will be included in the record, if you so choose. Why don't we begin with Ambassador Balton.

STATEMENT OF AMBASSADOR DAVID A. BALTON, DEPUTY ASSISTANT SECRETARY OF STATE FOR OCEANS AND FISHERIES, U.S. DEPARTMENT OF STATE

Mr. BALTON. Good morning, Mr. Chairman, Ranking Member Peters, members of the Subcommittee. I really do appreciate the opportunity to testify today. I do have a written statement and ask that it be included in the record.

Senator SULLIVAN. Without objection.

Mr. BALTON. As you said, Senator, marine debris is a large and growing global problem. It harms fishing industries through losses due to abandoned and derelict fishing gear. Floating debris fouls ship drives and poses major navigational hazards to oceangoing vessels, and it poses costs on the tourism industry, and, of course, it harms the marine environment itself.

Though marine debris includes various materials, one of the most common and troublesome is plastic. Current estimates indicate that there are already 150 million tons of plastic waste in the ocean, and, as you said, another 8 million tons added each year. Without action, there could be one ton of plastic for every three tons of fish in the ocean by 2025, and by 2050, there could be more plastic than fish by weight in the ocean.

No nation acting alone can solve this problem. Objects that enter the ocean in one location wash up thousands of miles away, making marine debris truly a transnational issue. Similarly, governments acting alone cannot solve the problem. Combating marine pollution effectively requires efforts from all stakeholders, public and private.

But the very visible nature of marine debris and the rapidly growing awareness of its cost has made it an issue of strong public interest. I'm happy to report that a large and growing number of international organizations and fora are now focusing on marine debris, and a growing number of stakeholders are working with governments to address the problem. My department, the Department of State, works with NOAA and other interested agencies, foreign governments, international organizations, private sectors, civil society to raise awareness of the problem and to push for remedial action. Let me just mention a few examples.

The Our Ocean conferences made marine pollution a real focus, producing significant public and private action. The 2016 conference alone yielded commitments of about $1 billion to address marine pollution and spurred partnerships of various kinds. The next Our Ocean conference, which will take place this October in Malta will again have marine pollution as a focal point.

The United Nations has also given marine debris increasing attention partly because of our advocacy and extensive work. The U.N. launched its Global Partnership on Marine Litter in 2012. Two weeks ago, a U.N. ocean conference in New York focused on implementation of Sustainable Development Goal 14, which commits all governments to reduce and prevent marine debris of all kinds.

In the G7, we are working to coordinate individual country initiatives, for example, by supporting additional research on microplastics and their impact on human health, improve scientific monitoring, and advocating for better use of resources to recover, reduce, recycle, and repurpose waste. Through the G20, we seek to connect with key developing partners, such as India, Brazil, and South Africa, with U.S. agencies to share expertise and to promote their capacity to become regional leaders.

As Senator Peters mentioned, we are party to the Marine Pollution Suite of Conventions adopted by the IMO, particular Annex V. We're also party through a protocol to the Cartagena Convention on land-based sources of marine pollution. Using this tool, we are leading an effort to make marine debris reduction a priority in the Caribbean region. In the South Pacific, we are using the Noumea Convention to provide financial and technical support to governments in that region.

Our current focus is on East Asia for the reason you stated, Mr. Chairman. Rapidly developing Asian economies are responsible for more than half of all plastic waste entering the ocean. It's clear that the growth of these economies has outpaced their capacity to manage waste.

Improving waste management infrastructure in these nations can dramatically reduce the amount of plastic entering the ocean.

So through APEC, partnering with the Japanese government, American industry, and conservation groups, we've brought together government officials, development banks, experts, and NGOs to spur financing for solid waste management systems in the Asia-Pacific region.

We also seek to work bilaterally. We are supporting Indonesia, for example, that has announced the goal to reduce its marine litter by 70 percent by 2025. Among other things, we sponsored Dr. Jambeck of the University of Georgia, one of the foremost experts in the field, to travel to Indonesia and to the Philippines and Japan and South Africa to catalyze action. We facilitated a sister city program between two American and two Chinese cities to share best practices on waste management.

These are some of the examples of the State Department's engagement. Thank you once again for the opportunity to testify. I'd be pleased to answer any questions.

[The prepared statement of Mr. Balton follows:]

PREPARED STATEMENT OF AMBASSADOR DAVID A. BALTON, DEPUTY ASSISTANT SECRETARY OF STATE FOR OCEANS AND FISHERIES, U.S. DEPARTMENT OF STATE

Mr. Chairman, Ranking Member Peters, and Members of the Subcommittee:

I appreciate the opportunity to testify today to discuss the role of the Department of State in working on the international stage on reducing marine debris. We have found regular communication between the State Department and our interagency partners helpful to ensure efficient and effective utilization of our combined resources and expertise in our global marine debris engagement.

Marine Debris: The Real Sea Monster

Marine debris is a large and growing global problem. It harms fishing industries through losses due to abandoned or derelict fishing gear that continue to capture fish stock but also by polluting marine habitats, thereby lowering seafood catches, and ultimately reducing food security. Floating debris fouls ship drives and poses major navigational hazards for ocean-going vessels, increasing costs for seaborne trade. It also imposes significant socio-economic costs, particularly for the tourism industry by forcing local, state, and national governments to spend millions of dollars cleaning up beaches or through lost revenue from tourists who choose to spend their vacations away from polluted marine environments.

Though marine debris includes various materials, such as glass, metal, cloth, and rubber, one of the most common, and troublesome, is plastic. Plastic is a major source of marine debris due to its widespread use—a function of its utility, durability, and low price. Globally, reliable estimates indicate that plastic use may double by 2025 and quadruple by 2050, leading to a dramatic increase in marine debris unless we take action. Current estimates indicate that there are *already* 150 million tons of plastic waste in the ocean, with another 8 million tons added each year. Without action, there could be one ton of plastic for every three tons of fish by 2025. By 2050, there could be more plastic than fish (by weight) in the ocean.

This plastic will not go away readily. Plastic can take hundreds of years to decompose naturally. Even worse, in many cases it degrades into smaller "micro plastic" fragments that are impossible to retrieve, but which enter the food chain when consumed by sea life.

This problem cannot be solved by one country alone. Objects that enter the ocean in one location can wash up thousands of miles away, making marine debris a fundamentally transnational issue. Plastic debris has been found in all of the world's waters, from our domestic waterways, the Arctic ice, and the most remote uninhabited Pacific islands. The very visible nature of marine debris, and rapidly growing awareness of its costs, makes it an issue of strong public interest. Increasingly, international fora are taking up the question of marine debris as the vast scale of the problem becomes understood.

Combatting marine plastic pollution requires efforts from all stakeholders, public and private. We welcome efforts by the U.S. private sector to work with governments and other actors to address the problem. Plastic products are ubiquitous in modern life because plastic is so useful and cost effective, and often without economically viable alternatives, which means that reductions or bans on plastic items cannot be the sole solution. The American plastics industry estimates it will more than triple the net exports of plastics to $21.5 billion by 2030. As a result, the U.S. private sector also seeks to promote sustainable and responsible plastics use, including by improving waste management in markets where waste leakage into the waterways contributes to marine debris.

Taking Action Globally

The Department of State, through the Bureau of Oceans and International Environmental and Scientific Affairs, is working with interagency, private sector, academic, industry, and non-governmental stakeholders to engage multilaterally, regionally, and bilaterally to address this increasingly pressing issue.

Our goal is to develop a comprehensive and coordinated approach that brings to bear the American expertise on this matter—both inside and outside of the U.S. Government—to others around the world.

For example, the Our Ocean conferences brought together diverse international stakeholders and underscored the importance of global cooperation—both from the public and private sector—to prevent and reduce marine debris. The conferences have yielded significant public and private action, including around $1 billion committed towards marine pollution alone in the U.S.-led 2016 conference in Washington, D.C. That marine pollution will remain a focus in the 2017 Our Ocean conference to be hosted by the European Union in Malta this October is a testament to the global commitment to reducing marine debris.

The United Nations has also given marine debris an increasingly prominent role in recent years, partly because the United States has worked extensively to elevate the issue within UN bodies. As you will hear from my colleague Nancy Wallace at NOAA, the UN's Global Partnership on Marine Litter was launched in June 2012. Since then, nations, including the United States, have worked in concert to prevent and reduce marine debris worldwide, while mitigating its impact on economies and human and animal health. The recent UN Ocean Conference, focused on the implementation of Sustainable Development Goal 14, put marine debris front and center.

The G7 and G20 fora are also opportunities to push for progress in tackling marine debris.

In the G7, we are working to promote better coordination of various individual country initiatives supporting additional research on micro plastics and their impact on human health, improved scientific monitoring, and advocating for better use of resources to recover, reduce, recycle and repurpose waste. We also support the G7 focus on working through the existing Regional Seas Programs and Regional Fisheries Management Organizations to address this issue.

In the G20, we seek to connect key developing G20 member partners such as India, Brazil and South Africa with U.S. expert agencies to share our expertise and to promote their capacity to become regional leaders in combatting marine debris. The G7 and G20 efforts complement the United Nations Environmental Assembly's work to implement regional marine litter plans of action.

The United States is a member of two Regional Seas Programs that engage neighboring countries to collaborate on preventing marine pollution of various types from entering the ocean. Through the Caribbean Environment Program, created in connection with the Cartagena Convention, we led an effort to make marine debris reduction a priority and instituted an initiative in partnership with the EPA to develop community-based trash reduction projects and create effective solid waste management policies. Projects in Jamaica and Panama are already underway and helping to keep marine debris out of the Caribbean.

We are also actively engaged in the southern Pacific, home to the Hawaiian Islands and U.S. territories and Freely Associated States, through financial and technical support under the auspices of the Convention for the Protection of the Natural Resources and Environment of the South Pacific Region, also known as the Noumea Convention. These measures directly affect the quality of life and act to preserve the environment for American citizens and nationals.

Combatting marine debris will require sustained concerted and comprehensive action. We need innovations in materials and design, dramatic changes in consumer behavior, and significantly improved waste management to significantly reduce the amount of marine debris. The solutions will also necessarily vary according to regional and national context.

For example, work by manufacturers on improved packaging design to reduce the use of plastics is necessary for the nations designing and producing plastic goods. But this solution does not translate to developing nations where many consumers are forced to use single-use plastic sachets of daily goods like soap and detergent, simply because they cannot afford to buy larger containers. We need different solutions to effectively fit the local realities.

Targeting Marine Debris at the Source

We are currently focused on reducing marine debris in East Asia as the best use of our resources to maximize our impact. Rapidly developing Asian economies are responsible for more than half of all plastic waste leaking into the ocean because their economic growth outstripped waste handling capacity. With just five countries in Asia generating more marine debris than the rest of the world combined, we can target interventions where they will have the most impact. Facilitating investment in waste management infrastructure in these developing nations can lead to dramatic reductions in plastics entering the ocean in a relatively short time.

In APEC, for example, we partnered last year with the Japanese government, American industry and conservation groups to convene a meeting of government officials, development banks, experts, and NGOs to spur financing for solid waste management systems in the Asia Pacific. We are now engaged with a wide range of stakeholders within the U.S. Government, with foreign partners, academia, the private sector, and NGOs in an effort to develop the next steps to tackling this problem at the source.

When appropriate, we are also working with key bilateral partners. For example, the Department of State is working closely with U.S. technical agencies and other partners to support the government of Indonesia's recently stated ambitious goal of reducing its marine litter by 70 percent by 2025. As part of that effort, we have sponsored Dr. Jenna Jambeck of the University of Georgia, who did ground-breaking work on sources of marine debris, on an Embassy speaking tour to Indonesia, the Philippines, Japan, and South Africa, which will provide multiple opportunities to connect one of the foremost experts in the field with policymakers, media, and other influential audiences to catalyze action.

We are also facilitating a program between the Chinese cities of Xiamen and Weihai and New York and San Francisco to share best practices on waste management to reduce and prevent the creation of marine litter. Both sides are working to develop an integrated waste management plan that can be used to reduce land-based sources of pollution in the marine environment. This follows a visit of Chinese officials to New York, Chicago, and San Francisco to see how U.S. cities have tackled the problem of marine litter by focusing on upstream preventative measures.

These are some examples of the State Department's engagement on marine debris in close coordination with our interagency colleagues and international partners. Marine debris, in particular marine plastic pollution, has consequential ramifications for the economy and food security directly impacting the United States. As the SOS bill recognizes, addressing marine debris is impossible without close international coordination. And the success of the Our Ocean conferences illustrates that American leadership can catalyze action to advance progress in our global efforts to combat marine debris.

Thank you once again for the opportunity to testify. I would be pleased to answer any questions.

Senator SULLIVAN. Thank you, Ambassador Balton.

Ms. Wallace.

STATEMENT OF NANCY WALLACE, DIRECTOR, MARINE DEBRIS PROGRAM, OFFICE OF RESPONSE AND RESTORATION, NATIONAL OCEAN SERVICE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

Ms. WALLACE. Good morning, Chairman Sullivan, Ranking Member Peters, and members of the Subcommittee. As you mentioned, I'm Nancy Wallace, and I'm the Director of the Marine Debris Program at NOAA within the Department of Commerce. I very much appreciate the opportunity to testify today on the issue of marine debris, and my full written testimony is submitted for the record.

Senator SULLIVAN. Without objection.

Ms. WALLACE. One of our biggest impacts to our oceans comes in the form of marine debris. Once treated as an infinite resource, the ocean is now overflowing with manmade items that do not belong there. These items invariably include things like beverage containers, cigarette butts, single use plastic bags, and other consumer products.

Marine debris ranges in size from derelict fishing gear and abandoned and derelict vessels to small plastic fragments and spheres that are less than 5 millimeters in size. Negative impacts of marine debris on the environment include: ghost fishing of marine species by derelict gear; entanglement of marine mammals, sea turtles, and other species; habitat destruction; and ingestion of debris of all kinds. Additionally, marine debris can create navigational hazards, cause significant economic loss, and affect human health and safety.

The NOAA Marine Debris Program leads efforts in the United States to research, prevent, and reduce the impacts of marine debris. Authorized by the Marine Debris Act and amendments, the program supports marine debris projects in partnership with state and local agencies, tribes, nongovernmental organizations, academia, and industry. Our mission is to investigate and prevent adverse impacts of marine debris. To accomplish this mission, our program is built upon five main program pillars: research, removal, prevention, regional coordination, and emergency response.

Research is critical to our understanding of the sources of marine debris and the adverse impacts that it has on the marine environment and humans. NOAA has funded research projects that focus on filling key gaps in our understanding of marine debris, such as evaluating the effects of micro plastic on marine species and assessing economic and environmental impacts of consumer debris and derelict fishing gear.

NOAA annually funds marine debris removal projects across the United States, including in logistically challenging locations, such as Alaska and the Pacific Islands. For example, we are partnering with the Sitka Sound Science Center on removal efforts in remote marine debris hotspot communities in the Bering Sea, such as St. Lawrence Island and the Pribilof Islands.

While removal can have immediate impacts on the marine environment, prevention is the ultimate key to reducing and eliminating marine debris. We like to use the analogy of turning off the tap. Improving waste management and infrastructure and facilitating behavior changes are some of the most effective ways to stop marine debris from entering the environment in the first place.

Currently, NOAA partners are working with communities around the country to create networks of local leaders for prevention efforts and educate the public on what actions they can take to help address marine debris. Such successful coordination and collaboration with our partners would not be possible without our regional staff that are located in 10 regions around the country. These regional coordinators are the boots on the ground for the program, leading efforts to develop state and regional marine debris action plans that outline the major goals for preventing and reducing marine debris based on local needs and issues.

As part of our final program pillar, emergency response, NOAA responds to events such as hurricanes, tsunamis, and flooding by leading detection, modeling, monitoring, and removal efforts in affected areas. The program is also proactively working with Federal, state, and local partners to develop marine debris emergency response guides for all coastal states.

Marine debris is a global problem that has local solutions. Every country faces unique challenges, and one size does not fit all. The most successful solutions take into account local knowledge and challenges as well as the best practices and lessons learned from across the global community. NOAA works very closely with the Department of State and participates in international efforts, including the United Nations Environment Global Partnership on Marine Litter, the G7 and G20 efforts, the Asia-Pacific Economic Cooperation.

Thank you again for the opportunity to testify about this very, very important issue. I'm happy to answer any questions you may have.

[The prepared statement of Ms. Wallace follows:]

PREPARED STATEMENT OF NANCY WALLACE, DIRECTOR, MARINE DEBRIS PROGRAM, OFFICE OF RESPONSE AND RESTORATION, NATIONAL OCEAN SERVICE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

Introduction

Good morning Chairman Sullivan, Ranking Member Peters, and members of the Subcommittee, thank you for this opportunity to testify on the issue of marine debris. My name is Nancy Wallace and I am the Director of the Marine Debris Program at the National Oceanic and Atmospheric Administration (NOAA) within the Department of Commerce.

Marine Debris, as defined by the Marine Debris Act, is, "any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment or the Great Lakes." Marine debris ranges from lost or abandoned fishing gear and vessels, to plastics, glass, metal, and rubber of any size, and is an on-going international problem that impacts our natural resources. The NOAA Marine Debris Program (MDP) leads national efforts to research, prevent, and reduce the impacts of marine debris. Authorized by the Marine Debris Research, Prevention, and Reduction Act and Amendments (P.L. 109–449, P.L. 112–213) ("Marine Debris Act"), the program supports marine debris projects in partnership with state and local agencies, tribes, non-governmental organizations, academia, and industry. NOAA spearheads national research efforts, engages with the Department of State and international organizations on global marine debris efforts, and works to change behavior through outreach and education initiatives.

NOAA recognizes that marine debris is a global problem and that there is no "one size fits all" solution to addressing this issue on national and international scales. A recent study estimated that of the 275 million metric tons of plastic waste generated by 192 coastal countries in 2010, approximately 8 million metric tons entered the ocean (Jambeck *et al.,* 2015). A large portion of the plastic was contributed by rapidly growing, middle-income countries whose waste management infrastructures are unable to keep pace with increasing economic growth and population sizes. Yet, even countries that have made considerable efforts to address plastic debris were still top contributors of mismanaged plastic. When paired with the fact that the Jambeck study addressed only plastic debris and not other substantial sources of marine debris, such as derelict fishing gear and abandoned vessels, it is clear that there is still much work to be done to find solutions to marine debris on both the national and international levels.

Today I will focus my testimony on the Marine Debris Act, the impacts of marine debris in the ocean and Great Lakes, and the program pillars of NOAA's MDP.

Marine Debris Act

The MDP is authorized by Congress as the Federal lead to work on marine debris through the Marine Debris Act, signed into law in 2006 and amended in 2012. The Act authorizes the Administrator of NOAA, through the MDP, to "identify, determine sources of, assess, prevent, reduce, and remove marine debris and address the adverse impacts of marine debris on the economy of the United States, marine environment, and navigation safety." (33 U.S.C. § 1952). The Act further directs the Administrator, through the MDP, to "provide national and regional coordination to assist States, Indian tribes, and regional organizations," "undertake efforts to reduce the adverse impacts of lost and discarded fishing gear on living marine resources and navigation safety," "undertake outreach and education activities for the public and other stakeholders" on marine debris issues, develop "interagency plans for the timely response to events," and "enter into cooperative agreements and contracts and provide financial assistance in the form of grants for projects to accomplish the purpose" of the Act. 33 U.S.C. § 1952(b)-(c). The amendment in 2012 reauthorized the program and directs NOAA to address and determine severe marine debris events. The Marine Debris Act is the only comprehensive Federal legislation that addresses all types of marine debris in the ocean and coastal environment.

Marine Debris Impacts

Marine debris causes significant threats not only to ocean and coastal environments and wildlife, but also to human health, safety, and navigation. Each year, countless marine animals, sea turtles, and seabirds are injured or die because of entanglement in or ingestion of marine debris. Additionally, debris can scour, break, smother, or otherwise damage important marine habitat, such as coral reefs and tidal wetlands, that serve as the basis of marine ecosystems and are critical to the survival of many important species. Derelict fishing gear, such as nets and crab pots, can continue to capture fish—something we refer to as "ghost fishing"—for years after they are lost. Not only does this affect the species that end up as bycatch in the lost gear by reducing the abundance and reproductive capacity of the population, but it also causes fishermen economic losses. For example, a recent study on the effects of derelict blue crab traps in the Chesapeake Bay by Bilkovic *et al.,* (2016) estimated that ghost-pot removal efforts increased harvest value by $33.5 million over a six-year period. There is also mounting concern over the potential for marine debris to serve as a pathway for the introduction of non-native species. An extensive literature review by Thiel and Gutow (2005) reported over 1,200 species associated with debris from sources all over the globe. Along with such ecosystem impacts, coastal communities collectively spend millions of dollars annually preventing debris from washing up on their shorelines and removing debris that does come ashore. It not only degrades the natural beauty of our coasts, but it threatens the safety of those who work and play there.

Marine debris also creates navigation hazards. Ropes, plastics, derelict fishing gear, and other objects can become entangled in vessel propellers or clog water intakes causing operational problems, while larger items, such as lost shipping containers, can become collision dangers. Such interactions with marine debris involve costly engine repairs and disablement. Abandoned vessels are another navigational threat in our coastal waterways that have become a serious marine debris problem in many states. The dangerous and costly impacts of these different types of marine debris affect both the recreational boating and commercial shipping communities, and NOAA is actively seeking partnerships with these communities to expand our area of knowledge and proactively address the dangers.

The NOAA Marine Debris Program in 2017

The MDP, guided by the Marine Debris Act, is focused around five program pillars: research, removal, prevention, emergency response and regional coordination.

Research

A key tenet of the MDP is research. Congress recognized the need for research that determines the sources and helps us understand the adverse impacts of debris on the marine environment and navigation safety. 33 U.S.C. § 1952(b)(1). The field of marine debris research is relatively young with many questions that need to be answered in order to advance our understanding of the relationship between marine debris and the environment. Over the past 10 years, NOAA has funded research projects focusing on the effects of microplastics on marine species, development of standardized methods for marine debris monitoring, and assessment of the economic and environmental impacts of derelict fishing gear and consumer debris. For example, the program funded a 2014 study that evaluated the economic costs of marine debris on beaches in southern California. Authors found that a twenty-five percent decrease in marine debris could result in ~$32 million in beach recreation benefits to local residents during the summer months (Leggett *et al.,* 2014).

Currently, NOAA is collaborating with several academic partners to quantify and characterize microplastic debris in the Mississippi River and how it may eventually affect the Gulf of Mexico. This study and others are working to fill critical knowledge gaps about microplastics and other debris types in terms of where it is coming from, where it ends up, and how it is impacting the environment. In continuing to fill such gaps, the program plans to fund new research projects in FY17.

Removal

Since its inception, the MDP has been actively involved in marine debris removal across the United States. A portion of the program's budget goes toward supporting removal projects annually, including locally driven, community-based marine debris prevention and removal projects that benefit coastal habitat, waterways, and wildlife including migratory fish.

Removal of marine debris can be logistically challenging, particularly in remote locations such as Alaska. NOAA is currently supporting a derelict crab pot removal and recycling effort by the Douglas Indian Association in Gastineau Channel, outside of Juneau, Alaska, aimed at reducing loss of commercial species to ghost-fishing. In the last few months, tribal members have worked with other partners such as the Alaska State Troopers to identify, quantify, remove, and recycle or return derelict pots as well as discussed data applications and steps forward. The program is also partnering with the Sitka Sound Science Center to remove marine debris from remote, marine debris "hotspot" communities in the Bering Sea, such as Savoonga on St. Lawrence Island and St. Paul in the Pribilof Islands.

Prevention

One of the most effective ways to reduce marine debris is through prevention, which requires that boaters, fishermen, industry, and the general public have the knowledge and training to change the behaviors that create marine debris. NOAA's robust outreach and education activities focus on improving awareness and changing behavior through developing and disseminating public information, and by partnering with and providing funding support to external groups including academic partners, local governments, and nonprofit groups.

One of the greatest challenges of prevention is finding effective ways to reach diverse audiences and help them discover how they can participate in local solutions to marine debris. The National Aquarium in Maryland, in partnership with NOAA, is working with underserved communities in Baltimore to create a network of leaders to spearhead prevention efforts such as community cleanup events and communication trainings. In Mississippi, Ship Island Excursions is using their ferry service as a platform to educate passengers, many of which are students from underserved schools, on the impacts of marine debris on the Gulf of Mexico, and how they can prevent the issue.

The materials and products from our other partnerships, such as marine debris curricula, are all free and downloadable from the *MDP website,* and the program's regional coordinators do extensive boots-on-the ground outreach year-round to promote and share these products.

Regional Coordination

Working with non-governmental, regional, and international organizations, academia, and local, state, and Federal governments will enhance marine debris efforts across the country. The program's regional coordinators extensively cover marine debris issues in the Pacific Islands, West Coast, Alaska, Great Lakes, East Coast, Gulf of Mexico, and Caribbean. While these coordinators focus on the local, state, and regional issues as a part of the national program, they also bring in lessons learned and make connections across the country and the world.

NOAA is leading an effort with states to develop *marine debris action plans,* which outline major goals for preventing and reducing marine debris. Marine debris action plans are complete for Virginia, Florida, the Great Lakes, Oregon, and Hawaii, with plans in progress for the Gulf of Maine, Mid-Atlantic, Southeast, California, and Alaska. NOAA also continues to work with partners throughout the country to develop and test innovative and cost-effective methods of detection and removal of marine debris, and to engage the public and industry, including shippers and fishermen, and the recreational community on marine debris.

Emergency Response

Coastal storms and natural disasters are another source of marine debris that create hazards in our inland and coastal waters. NOAA has responded to emergency events including Hurricanes Katrina and Rita, the American Samoa and Japan tsunamis, and Superstorm Sandy. Following the Japan Tsunami, the program spearheaded detection, modeling, monitoring, planning, and removal efforts for debris from Japan that made its way to U.S. shores. NOAA also contributed initial funding to the states of Hawaii, Alaska, Washington, Oregon, and California for removal and response efforts, and was responsible for administering the monetary gift from Japan of $5 million under the Gift Act, 15 U.S.C. § 1522, to assist with debris removal in these states. Similarly, following Superstorm Sandy, NOAA worked with the affected states (Rhode Island, Connecticut, New York, New Jersey, and Delaware) on debris modeling, surveying, and removal using funds from the Disaster Relief Appropriations Act of 2013.

NOAA also works with federal, state, and local partners to develop *Emergency Response Plans* that outline the processes and roles of each partner for responding to and recovering from a severe marine debris event, such as a hurricane. To date, plans have been completed for North and South Carolina, Georgia, Florida, Alabama, and Mississippi, and plans for Louisiana and Virginia are currently in progress.

National Coordination

As mandated in the Marine Debris Act, 33 U.S.C. § 1954, NOAA is the chair of the Interagency Marine Debris Coordinating Committee (IMDCC), a multi-agency body that is responsible for streamlining the Federal Government's efforts to address marine debris. Representative agencies coordinate a comprehensive program of marine debris activities and report to Congress every two years on research priorities, monitoring techniques, educational programs, and regulatory action. Members include: Departments of State, Interior, Justice, and Homeland Security; U.S. Navy; U.S. Army Corps of Engineers; U.S. Environmental Protection Agency; and the U.S. Marine Mammal Commission.

This IMDCC Progress Report provides an update on the activities of Federal agencies to address marine debris, as mandated by the Marine Debris Act. In 2008, the IMDCC delivered the *"Interagency Report on Marine Debris Sources, Impacts, Strategies, and Recommendations."* Subsequent biennial progress reports have evaluated progress in meeting the purposes of the Act and these recommendations.

In addition to the IMDCC, the program also partners with other agencies on funded projects, such as a recently completed collaboration with the National Park Service and Clemson University that collected and analyzed beach sediments to assess the abundance and distribution of microplastics and microfibers on U.S. National Park beaches. NOAA has also been contributing to a multi-year, multi-partner effort between the U.S. Fish and Wildlife Service and others to remove debris from the Northwest Hawaiian Islands. In April 2017, ~100,000 pounds of derelict fishing gear and plastics were transported from Midway and Kure Atolls to Honolulu, and incorporated into the Hawaii Nets-to-Energy program, a highly successful strategic partnership between agencies, industry, and local partners. NOAA, the City and County of Honolulu, the State of Hawaii, Covanta Energy Corporation/H-Power, and Schnitzer Steel Industries, Inc. work together to convert derelict fishing gear and plastics into energy. Since its initiation in 2002, this program has created enough electricity to power over 350 homes for a year in O'ahu. NOAA plans to foster similar collaborations with other agencies and industry partners moving forward.

NOAA has also worked extensively with the U.S. Coast Guard (USCG) on contingency and emergency response planning on the West coast and in the Southeast and Gulf of Mexico, respectively. Additionally, the USCG provided valuable sighting reports of marine debris from the Japan tsunami to NOAA's Office of Response and Restoration (OR&R), which houses the MDP. From these data, OR&R was able to generate trajectories for locating and removing debris items that landed on U.S. shorelines.

International Engagement

Marine debris is a global problem that has local solutions. In many countries, population size and consumption of plastic and other consumer debris are increasing more quickly than the capacity to manage waste, and thus solutions must be shaped to address country-specific challenges. To help others move forward in finding their own unique solutions, NOAA works closely with the Department of State and participates in other international efforts including: the U.N. Environment Global Partnership on Marine Litter (chair), the G7 and G20 Marine Litter Cooperation, the Global Ghost Gear Initiative, the Asia-Pacific Economic Cooperation (APEC) (co-chair), the North Pacific Marine Science Organization (co-chair), the African Marine Waste Network, and implementation of Indonesia's National Action Plan on Marine Plastic Debris. As the APEC co-chair, NOAA is working to increase collaboration with industry and non-government organizations, such as the American Chemistry Council, Ocean Conservancy, and other international partners that will help address the diverse waste management challenges around the world to minimize the amount of marine debris.

NOAA is also working with the U.N. Environment Programme to help organize and facilitate the 6th International Marine Debris Conference in San Diego, California, March 12–16, 2018. The conference will bring together more than 600 participants from around the world, ranging from policy and decision makers, to waste management representatives, scientists, private industry, and civil society as well as facilitate connections, provide an opportunity for participants to exchange information and individual recommendations, and transcend geographic boundaries in the fight against marine debris.

Conclusion

All marine debris comes from humans, and thus it is a problem we can, for the most part, prevent. NOAA will continue to pursue on-the-ground research, prevention, and reduction of marine debris nationwide and work with international and other partners to find solutions that fit the unique challenges posed by marine debris, particularly with respect to waste management. While the problem of marine debris has existed for decades and has received considerable attention from NOAA and other partners, there is still much to learn as we work to address the impacts of marine debris on the environment, marine species, and human health and safety. NOAA is committed to investigating and preventing the adverse impacts of marine debris, and looks forward to working with the Committee to achieve our vision of seeing the global ocean and coasts free of debris.

Thank you very much for the opportunity to testify about this important issue. I would be happy to answer any questions you may have.

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Senator SULLIVAN. Great. Thank you, Ms. Wallace.

Let me begin with some questions for both of you.

Ambassador Balton, it was noted in your testimony about the challenges that we have with regard to the contributions of ocean debris and trash from countries in Asia, particularly the five that I noted in my testimony. Why are these countries such great contributors to trash in our oceans? What is driving this?

Mr. BALTON. I think the simple answer to that, Senator, is that their pace of economic development is just moving ahead so much more rapidly than their waste management capabilities. So to get a handle on this, we really need to help them improve waste management processes.

Senator SULLIVAN. So is it also a cultural issue, though, as well in terms of—and I'm not talking about the culture in Asia. I'm talking about a culture of recycling, you know, litter. Are there more things—it's economic growth, but is it also kind of the recognition that this isn't a problem?

Mr. BALTON. I think we certainly have a greater level of recognition here in the United States, perhaps in Europe and other developed countries. But take Indonesia, for example. They have announced the goal to reduce by 70 percent their marine pollution by 2025. That strikes me as reflective of a culture that cares about this issue and wants to take action. I think we can use that, Indonesia's example, and hold that up to some of the other Asian states as the type of steps that they should be taking.

Senator SULLIVAN. Let me follow up on that. You know, in the Save Our Seas Act, one of the important elements of it is that it encourages the administration and the Department of State to become more engaged with the world's leading marine debris producers. Your testimony, I think, did a really good job of laying out what is happening, and it's not inconsequential. There's obviously a lot of effort on this, whether it's individual countries like Indonesia or the U.N. or the G20 or G7. You mentioned it's come up in a lot of different fora.

But what specific opportunities do you see for U.S. leadership in this area, as we have encouraged in our bipartisan bill, and to focus on results?

Mr. BALTON. Given that a big part of the problem is in Asia, probably the best forum is APEC, the Asia-Pacific Economic Cooperation forum. It has already proven itself willing as a forum to provide a venue for dealing with these issues. The other economies seem willing to use APEC for this purpose. So we have ways of channeling technical and financial resources to countries in question. Through APEC, we have programs we can push forward through APEC. I would point to that as one particularly promising place for U.S. leadership. ASEAN might also be used in parallel. We have not used ASEAN so much as we might. So I could consider going there.

We have some higher level opportunities. The Our Ocean conference series that we inaugurated here in the United States is moving forward. I mentioned earlier the next conference will be in Malta. They want the—and the EU will host it. They want to focus on marine pollution again as a main topic. We can press for commitments there.

In the Caribbean, the South Pacific, we have Regional Seas programs that we're members of. We can use them. And here's one thought that we have not done enough about. The regional fishery management organizations that exist in the world could do more to deal with the problem of lost, abandoned derelict fishing gear. I think we should be using them.

Senator SULLIVAN. Well, look, we want to work with you on all of these opportunities. When we introduced this bill, I've had a number of leaders from different countries express interest in cooperating with the United States. I think there's a lot of encouragement, but I also think there's a recognition that, globally, this is not going to really happen in terms of solid results unless the U.S. is one of the key leaders, and that's part of what we're trying to do in the bill.

Ms. Wallace, let me ask you a couple of questions in my remaining time here. First, thank you for the work that you're doing in Alaska and the rest of the country. Two quick questions. You talk about your association with other groups, local groups. What can Congress do to better assist you with your efforts at NOAA?

And, then, more specifically, you talk about research, and particularly micro plastics and how they impact fish. As you know, in Alaska right now, we have salmon runs happening throughout our wonderful state. The biggest salmon runs on the planet Earth are taking place right now. What happens with regard to micro plastics in fish like salmon? Has the research indicated any kind of negative impact that you've been able to see?

Ms. WALLACE. Thank you for those questions. I think to answer your first question in terms of support that Congress can give, what I want to say most is thank you for the support you're already giving. Having a hearing like this, bringing attention to the issue, is incredibly helpful. I think working with the local partners that we work with in your state has been incredibly valuable. They're doing amazing work, and Congress has a substantial reach. So if constituents call and say, "What can we do to help this problem?", the answer is join a cleanup, think about what you're using, recycle, don't litter. You know, there are some real simple actions that can have a big impact.

To the second question on micro plastics, we are doing a lot of research on micro plastics. We're looking at what the impacts of micro plastics are on commercial fish species as well as invertebrates. So, for example, in oysters, we know that when oysters ingest micro plastics, it can affect their ability to reproduce. So there is an impact, and we need to continue to do research.

In Alaska, we've been working with the Auke Bay Lab to really look at what juvenile salmon are eating. Do they eat small pieces of polystyrene, or do they try to avoid it? If they do eat it, what happens to them? I think those studies are still ongoing, and we have more to learn. But there certainly is concern. These are commercially caught species and we want to learn more about those potential impacts are up the trophic chain.

Senator SULLIVAN. Great. Thank you.

Senator Peters.

Senator PETERS. Thank you, Mr. Chairman.

And, again, thank you to our witnesses here today. I appreciate your testimony.

Ambassador Balton, you have discussed both in your opening comments as well as questions from Chairman Sullivan the work that the Department of State is doing around the world in collaboration with other countries and coordinating with other countries. But given the issues that we have in the Great Lakes, which I outlined in my opening statement, the country that has an impact with that is Canada. So I would be interested in what ways is the U.S. collaborating with Canada on debris in the Great Lakes and in the region, and can we be doing a better job? What are your suggestions?

Mr. BALTON. We do cooperate with Canada. They are quite likeminded with us. They see marine debris pollution in the Great Lakes included as a significant problem. We have a couple of bilateral mechanisms we can use, including something set up by the International Boundary Waters Treaty 100 years ago. That's a good forum for that. We also have the Great Lakes Fisheries Commission that can deal with problems of lost, abandoned, derelict fishing gear. So those are some of the avenues I see for moving forward with Canada. I think we're pushing on an open door with them. They want to do more with us.

Senator PETERS. That's good to hear. Ambassador Balton, the administration has proposed cutting roughly about 30 percent from the State Department budget, and I'm sure that a cut of that magnitude will have significant impact on a lot of what the State Department does. Would you address what that kind of cut could possibly mean to our international efforts to deal with the marine debris problem?

Mr. BALTON. Senator, I guess I'd answer your question this way. I've been at the Department coming up on 32 years. I've seen our budgets rise and fall. The role of the State Department that I've outlined here is one of advocacy, convening, sending experts around the world. It doesn't cost a great deal of money. These are not high-dollar programs, and I'm reasonably confident that whatever our budget is in Fiscal Year 2018 and beyond, we will be able to continue to do this type of work on an issue as important as this.

Senator PETERS. Director Wallace, conversations on marine debris seem to always lead to more questions than answers. This is a very complicated subject, and we're starting to delve into that with this hearing as well as the other work that we're doing. But one of the top tier issues that was identified in the Great Lakes Marine Debris Action Plan was the need to just further refine the scope of the problem and better define what is really currently known about some of these issues.

In your estimate, what are some of the biggest gaps in our knowledge when it comes to the marine debris issue?

Ms. WALLACE. Well, I think the Great Lakes Action Plan was a real model for that conversation, and just to share, we did have great participation from Canada in the Great Lakes Action Plan as well. One of the emerging issues I think we're hearing more and more about that we'd like to do more research and understanding on is the microfiber issue. Micro plastics is getting a lot of attention and there has been great work at reducing the sources around potentially micro beads. But what we're learning now is microfibers that can come off our clothes are actually a huge issue as well. So I think in terms of research, looking at how we may be able to prevent that source of debris and also looking at what the potential impacts are around that source of debris are important.

Senator PETERS. So we, as you know, last Congress, passed the Microbead Free Waters Act, which dealt with microbeads. Do you think something along that line may be necessary for microfibers, or is it still too early to know that? What should be our path forward?

Ms. WALLACE. Well, I think you made a great point before about always raising more questions. So I think with the microfiber, we'd have to look at how you would do that. So I think that's where the discussions would come in, you know. Is there some sort of technology that can help to eliminate the fibers going through waste water treatment plants? With the microbeads, we know exactly where they are. They are in our cosmetic products. So having passed that legislation really helped prevent a specific source of debris. So I think it would be great for all types of debris to start looking at how we prevent those specific types of debris.

Senator PETERS. Great, thank you. And, finally, could you talk a little bit about how NOAA measures progress in addressing marine debris on a regional basis, specifically, the Great Lakes. As you're looking at what is truly a global problem, but a significant one, the Great Lakes, regionally, how are NOAA's efforts used to review that?

Ms. WALLACE. Well, I think the Great Lakes Action Plan, as I said, is a model, and what we like to do is because there are such different types of debris issues in different places, we can really focus on measuring success. So in the Great Lakes, specifically, looking at how much debris we've removed. So we've partnered with the Alliance for the Great Lakes, for example, in Belle Isle to remove lots and lots of debris.

We can also have monitoring programs that look at statistically robust—getting people out on the shorelines to count how much debris is out there. Over time, we hope to be able to reduce it. And we also measure success by how many people we're reaching, so getting that prevention message out. In 2017 alone, we've reached over 16,000 K through 12 students, which is a great number, and we'll continue to do that, because I think behavior change is a big way we are going to make success happen.

Senator PETERS. Right. Thank you, and thank you for your efforts. Appreciate it.

Ms. WALLACE. Thank you.

Senator SULLIVAN. Senator Inhofe.

STATEMENT OF HON. JIM INHOFE, U.S. SENATOR FROM OKLAHOMA

Senator INHOFE. Thank you, Mr. Chairman.

You know, I never realized there was such an issue or there was a problem until Senator Sullivan was elected and made it very clear to me the problem that exists up in his area and the source of that problem. But that got me interested in another area, because back in the real world, I was a builder and developer in south Texas, back when I enjoyed life.

I remember so well during that time—in fact, do you remember the Ridley sea turtle? It was started by Ila Loetscher. She died at 100. She and I used to work together as long as 60 years ago on some problems with that particular—very few places where they breed and that happened to be one of the places.

Now, the reason I'm bringing this up is that this has become—some of these have been a problem down there, but nobody talks about it down in south Texas. I notice that most—you talk about in Asia and where the problem is.

And you mentioned, Ms. Wallace, in your testimony that they picked up—Cartagena Convention. Now, when was that?

Ms. WALLACE. Excuse me?

Senator INHOFE. The Cartagena Convention.

Ms. WALLACE. I'll turn that over to Ambassador Balton.

Senator INHOFE. I thought you said—you were the one who referenced it.

Mr. BALTON. I may have mentioned that, Senator. The original Cartagena Convention, I believe, dates about 30 years ago. But there was a protocol to it on land-based sources of marine pollution that is more recent—I want to say in the 1990s—and we became party to it probably in the late 1990s. Anyway, it's a tool for working with other countries in the Caribbean region on this.

Senator INHOFE. Yes, that's right. And, by the way, I appreciate very much your answer to the question that was asked of you, because quite often—I know there are dedicated people that you work with—and you've been there for a long time—who are going to see to it that these programs are carried on, in spite of having to tighten up a little bit in fiscal things.

Now, the reason I mentioned the Cartagena Convention is because that focused on the projects—I think you had a project in Jamaica and in Panama——

Mr. BALTON. Yes.

Senator INHOFE.—getting closer to the area where I worked for some 15 years. Now, I would assume that the same problems exist in some of the Mexican areas and Central American areas as do in Asia. And the reason I bring this up is because, in that case, they say that there's an ingestion of something that is affecting in a negative way the Ridley sea turtles, and, in fact, just as recently as two months ago, I was down there talking about that.

Can either one of you—are you familiar with—in that area—I know that's not the area of concentration in this committee—but what that might—how they might be affected?

Ms. WALLACE. I can take that one. So, yes, I think you're absolutely right. We need to work more with our partners to the south, specifically in south Texas. We have monitoring programs around South Padre Island that just show a massive, a massive, amount of debris washing ashore, especially the way the currents bring the water and the trash up from Mexico, and certain debris items you can certainly track back.

So that's something that we are working on very strongly. We have some grants with groups in south Texas to do a lot of removal and prevention, specifically around the sea turtles, and prevention around sea turtles, how to make sure we're not impacting them, because sea turtles can certainly ingest things like plastic bags or other debris items that can be a big problem.

We also have some really strong partnerships in southern California and the San Diego area, where just over from Tijuana, there's trash coming into the Tijuana River. So we have provided funding to set up booms that will actually catch that trash before it goes out into the open ocean. But we're also working on prevention efforts in Tijuana as well.

Senator INHOFE. Well, I'm very interested in that area down there. You know, I can remember back when the big issue was turtle exclusions from shrimp boats, and we had very positive results getting involved in that. So there can be some things that we help with. So what I would ask of either of you is to kind of help me be informed, because I work with those people still on a regular basis, and there are a lot of people down there concerned about that, and I think they need a little guidance, because until this hearing came along, I was not aware of that. So if you will keep me informed about that particular area, it would be very helpful.

Mr. BALTON. Yes, sir.

Senator INHOFE. Thank you.

Senator SULLIVAN. Thank you, Senator Inhofe, for those questions.

Senator Booker.

STATEMENT OF HON. CORY BOOKER, U.S. SENATOR FROM NEW JERSEY

Senator BOOKER. I'm really grateful. This is an important hearing. It's an issue I've been pushing and pounding away on since I introduced a bill in the last Congress. In absentia, I just want to say how grateful I am to Senator Sullivan for picking this up, being a champion, making more people aware of it, and for the generous comments by Senator Inhofe about Senator Sullivan's leadership in making people aware, and I'm psyched about the bipartisan efforts that are going on right now.

But the problem is that every time I sit down to read about this problem, I realize that it is far more dire than we are expressing, and that the reality is despite all of these really good efforts, we are barreling toward a crisis of global proportions. So the amount of plastics being poured into our oceans—the amount of plastics, period, has increased 20-fold in the last 50 years, and that curve of increase in plastics production is not being bent. And with the onslaught of shipping stuff around the world, the expanding globalization, this production of plastics is just growing and growing and growing.

It's nice also that we're talking to other areas on the planet Earth about their problems. But in the United States, we recycle only 8 percent of this plastic. The rest of it goes into two channels, one into our landfills, which we may think is okay, but we'll talk about the carbon problem in a second, and the other—a third of it ends up in our oceans and our waterways.

So, again, I'm excited about the progress we're making, but I really do feel like we are on our hands and knees crawling in the foothills, and there's an Everest of a problem that is screaming toward us that we don't seem to understand. It is terrifying when I sit down and read the problem. And, frankly, there are enough reasons already that our grandchildren should be ticked off about this generation and what they stuck them with. But what our children are going to inherit is unconscionable.

You know, right now, we have about a third of all plastics, as I said, escape the ecosystem—escape collection systems, rather, and wind up floating in the sea or in the stomachs of our animals and birds, and that amounts to 8 metric tons a year right now, before the increase. Now, that's about five plastic—five bags filled with plastic for every foot of coastline in the world. We throw out these numbers and people don't seem to grasp how much plastic is out there right now. For every foot of coastline on the planet Earth, you can have five plastic bags full of this stuff.

Plastic production accounts for so much of our oil consumption, but that's going to increase. Right now, it's 6 percent. Soon it will be 15 percent of our oil production that is going into producing plastics, and the crazy thing is the carbon emissions alone by 2050 will be accounting for 15 percent of the carbon emission budget that we have before we go to points of no return. I'm so encouraged by the bipartisanship partnership on this. But it is just not enough.

So, Director Wallace, please, could you help—just put—honestly put aside your—the encouraging efforts that are going on that are really good to see. But could you let me know your personal sense of alarm at the nature and gravity of the global crisis we have, that by 2050, we will be in a state of planetary peril. Would you please tell me if I'm not—am I exaggerating that, in your personal opinion?

Ms. WALLACE. This is an alarming issue. It is. And I think we do need to pay attention to it. I am happy that we're here talking about this. It's something I work on every single day, so I do have to have a sense of optimism. Otherwise, it would be a hard job to have.

I think you're exactly right. One of the things that we keep talking about is, you know, the biggest polluters in that study that we're mentioning, the Jambeck study, are in Asia, the five biggest countries. But the United States is number 20, and we are the number one generator of waste in the world. So we are contributing to this problem, and I think what we need to do is to raise some alarm bells to say this is a big issue. It is something we can change. There are actions that we can take. We can absolutely use less, generate less waste——

Senator BOOKER. Ms. Wallace, can I just—because my time has expired. But I just need to say this. I've learned the hard way from inner city Newark, New Jersey, that hope does not exist in the abstract. It is a response to despair, saying despair is not going to have the last work, and I'm going to be an agent of hope. And hope is not just some sit back and, like, let's pray things change. Hope gets up in the morning, rolls up its sleeves, and goes to work.

And the hope has got to be changing the culture of our planet, and in this country, we want to lead on this issue. Why aren't we leading in discovering new ways to wrap our products that don't involve petrochemicals and that are biodegradable? Why aren't we changing the habits in our cities and in our towns of plastic bag use and all of this?

This is a crisis of global proportions, and we're acting as if the little teeny bit that we're doing is somehow going to stop our grandchildren from experiencing a world where there is more plastic—I hope to be alive in 2050—more plastic in our oceans than all of the fish and marine wildlife. That is where we're heading. In fact, we could be getting there quicker with the onslaught of globalization and how many packages I order from Amazon Prime, and I could go on and on and on about that.

So that's my thinking, is that we—this is a great early step in this crisis. But we've got to start doing a lot more aggressive things if we're going to actually avert a disaster that we see coming toward us. Every scientist, every report, from the World Economic Forum to the Journal of Science event, everything I can get my hands on, says we are heading screaming toward a level of peril that our efforts right now don't seem to fully grasp.

Thank you, Mr. Chairman.

Senator SULLIVAN. Well, I want to thank Senator Booker for his leadership on this issue and obvious passion, and I think it's what we need, and it's much appreciated.

Senator Schatz.

STATEMENT OF HON. BRIAN SCHATZ, U.S. SENATOR FROM HAWAII

Senator SCHATZ. Thank you, Mr. Chairman.

I thank the Chairman and the Ranking Member as well as the Senator from New Jersey for their leadership on this issue. This is a bipartisan issue. It's important to me for obvious reasons.

Ms. Wallace, I wanted to ask you about the garbage patch in the Pacific. Let's just do it this way to start. Describe it for us.

Mr. WALLACE. Yes. The garbage patch has gotten this amazing sort of reputation that maybe it doesn't deserve. I think people think about an island of solid trash out in the middle of the ocean twice the size of Texas. That's what we hear, right? But what it actually is is the North Pacific Gyre. It's a convergence zone, where things that don't have propulsion on their own will end up. So it's a collection area.

But it's not a solid land mass. It's bundles of fishing gear. It's tiny pieces of micro plastic that can be spread miles apart and throughout the water column around the benthic surface. So you can actually sail through the garbage patch without necessarily knowing you're there.

Senator SCHATZ. It's just covered in trash.

Ms. WALLACE. Well, it is, but it's not—you may not see all the trash, right, so it's not this big solid land mass. It's actually kind of all spread apart. We've used the analogy of a peppery soup, if you think about it, so these little pieces that are flowing throughout.

Senator SCHATZ. OK. Thank you. And then when it comes to marine debris and marine trash, what is the composition of marine trash on the planet, if we know this, between sort of maritime uses, between dumping, between sort of landfill practices that are not best practices? In other words, where is this all coming from?

Ms. WALLACE. That's a great question, and it is something that we don't necessarily have the exact answer to, but I can certainly tell you there is a mix of land-based and sea-based sources. For instance, in the northwestern Hawaiian Islands, we know that we accumulate 50 tons of derelict fishing gear a year in this pristine environment.

But if you look at the Ocean Conservancy's International Coastal Cleanup Data, the past 30 years of picking up trash on the beach, the number one item is almost always cigarette butts, followed by plastic bottles, plastic bags, consumer debris. So we know that a huge amount is these land-based sources of debris. NOAA has a monitoring program to try to get at that more.

Senator SCHATZ. So we don't know?

Ms. WALLACE. Well, I think there's a number that we hear a lot, sort of 80 percent land and 20 percent sea, but I think it really depends on where, specifically, you're looking. To get a real global estimate is hard. But we know it's all bad.

Senator SCHATZ. Sure. But from the land-based trash, is this—are these landfills that are along the coastline and trash that ends up in the ocean, or is this the dumping of land-based trash into the ocean?

Ms. WALLACE. In the United States, I would say a lot of it is coming from sort of mismanaged waste, things that flow off garbage trucks, maybe don't get put into garbage cans, littering. But it can come all the way down through the river, so it doesn't necessarily have to be your beach debris. Here in Washington, D.C., we know things are coming straight down the Anacostia River into the Potomac and out into the Chesapeake Bay. So it doesn't necessarily come just from our people that are right on the shores. It's coming from all over.

Senator SCHATZ. The reason I'm asking this is not just to satisfy my curiosity, but, obviously, we want to know where it comes from so we can figure out how to go upstream and stop it.

Ms. WALLACE. Right.

Senator SCHATZ. And, you know, Senator Booker talked eloquently about the need for behavior to change and the need for some of our societal norms to change, and the good thing is that we're innovative enough to still have a convenient life and reduce the amount of waste we put into landfills and then accidentally put into the ocean. But the question that I have—and I'm troubled because I have some pretty good experts on my own staff, and they have accessed other experts—that we don't really know from whence all this comes and how to go upstream and determine—especially in the international context—what do we do about the poor management of landfills, for instance, in Southeast Asia, you know? We just don't know what percentage of the problem this comprises.

Ms. WALLACE. Right. So I think, you know, in the United States, one of the things we're doing is we have robust monitoring programs. So it's a small thing, but we can start to see what the biggest items are in specific areas.

Our partners in Virginia find tons and tons of balloons on their beaches, and if we didn't have that monitoring data, we wouldn't know. But knowing that they're balloons, maybe we can do a really big push on education, saying, "Hey, don't release your balloons into the air." In Washington, we found a lot of aquaculture debris. We can go to the aquaculture industry and say, "This is a problem. We have the data."

In developing countries, I think it's a very different story. I think we need to really think about the financing and the value around waste and how we incentivize that value and that collection. So there are different solutions depending on the different places that you are.

Senator SCHATZ. Mr. Balton, do you have anything to add?

Mr. BALTON. No. She said it perfectly.

Senator SCHATZ. Thank you.

Senator BOOKER. Mr. Chairman, can I just submit for the record——

Senator SULLIVAN. Sure.

Senator BOOKER.—because I think what I would really like for you and I and others to consider is what these two experts—what are some of the things that are not being done or not being suggested by the legislation put forth, if they would prioritize significantly for Congress to be looking at doing. I think an action plan that might be more ambitious for us to consider would be really helpful if we could submit that for the record.

Senator SULLIVAN. Well, yes, why don't we do that in terms of our witnesses, all three witnesses today, and if Senator Whitehouse has the opportunity to make it, he's going to be another witness. But I think that's a good idea. We have legislation that, I believe, is supported by the administration. We're certainly encouraging you to take additional steps. But if you can provide us suggestions for what's not in the legislation but you still think we need to prioritize, I think that would be a very helpful exercise.

We'd like to give you as much time as you need to come back to us, because we'd like you to get that right, and we'd like to get some kind of consensus on it. I think it's an excellent suggestion.

Senator Cantwell.

STATEMENT OF HON. MARIA CANTWELL, U.S. SENATOR FROM WASHINGTON

Senator CANTWELL. Thank you, Mr. Chairman, and I want to thank Ms. Wallace for, you know, this—in another iteration, obviously, the tsunami debris which you helped Alaska, Washington, and Oregon deal with some of that debris, and we so appreciate it, because here we were—this similar issue but, obviously, a different cause, and left with a cost—I think in one instance, we had a major dock show up on the Oregon coast, which was—who was going to remove that? This wasn't like a weekend crew of people. So the cost of all of this debris does affect our fishing community, our coastal community. So thank you for that.

I wanted to bring up the issue of derelict vessels and—well, to either of you, really. I mean, the GAO recently completed a study on abandoned and derelict vessels, and we had this Davy Crockett, which was a derelict barge in the Columbia River, and it spilled 1.6 million gallons of oil in the Columbia River, and it cost $21 million to clean it up. So the GAO in their study found that there were significant gaps in who owned this issue.

So I wanted to hear from both of you what—you know, the Coast Guard is responsible for removing the oil and hazardous substance but not the vessel; the Army Corps, if it is deemed a navigational hazard. So you could have a derelict vessel that wouldn't be deemed a navigational hazard and there it would be, sitting there for a long time.

So what is NOAA's role, Dr. Wallace, and what do you think we should be doing to create more certainty and predictability for our communities about removing derelict vessels?

Ms. WALLACE. Abandoned and derelict vessels are a real problem, and I think a lot of people may not think of them as marine debris, but they are. For NOAA, we have the ability to provide funding, and we do so through competitive grants, to remove vessels. But it certainly is not enough funding or comprehensive enough to remove every derelict vessel.

So one of the things that we've been able to do is work with different states who have different programs. Washington, in particular, has a very good program about collecting fees that can then be used to remove those vessels when they become derelict. So we've been working with states to help share that information. In Florida, they have a great program, a vessel at risk program, where there's a lot of enforcement around identifying which vessels may become derelict and using preventative measures through enforcement opportunities to help maybe make them not become derelict.

But I think it is a gap, and I think that GAO report showed that very clearly. If there isn't a responsible party, and if there isn't a navigational hazard or oil and gas situation, it does become sort of the problem of the local landowner, which is not right, and that's where we are right now.

Senator CANTWELL. Do you have a recommendation?

Ms. WALLACE. Well, I think there are more things we can do to help prevent them. That's the best thing we can do. If there's vessel turn-in programs, in some states, that's an opportunity. So if you—it costs a lot of money to dispose of a boat appropriately. So there are kind of these opportunities—certain weekends when people can go and dispose of their boats free of charge. I think that would be great. And, also, these vessel-at-risk programs, expanding them, and then looking for areas where we might be able to have funding through local programs that then would help address when a vessel does become derelict.

Senator CANTWELL. Mr. Balton, any comments here about derelict vessels?

Mr. BALTON. Only this. I'm glad you raised that, because we have been focusing almost exclusively, until this point in the hearing, on plastic pollution, which is, of course, a serious problem. But, as you point out, there are other serious categories of marine pollution. You mentioned one. I might mention a couple of others. We have nutrient pollution. Excess nutrients flow off of, for example, agricultural areas, out rivers and the creek dead zones in the ocean. There's some 600 of those around the world. We have oil pollution problems still around the world.

So in looking at marine debris, it's important not to lose sight that there are many different types of pollution, and they are amenable to different types of solutions, unfortunately. But they're all important.

Senator CANTWELL. Well, I thank my two colleagues for having this hearing, and I thank the witnesses, and I hope we do spend time on this aspect of it. We had another incident up in our shellfish industry in the North Sound. We had another derelict vessel, and it shut down the industry up there. So these can be more than just an eyesore. They can be a real threat to the environment and activity, and I just think this gap between Coast Guard and Army Corps and NOAA is still something we should think about.

I'm all for partnership, and I like the idea that you're saying that you might be able to prevent some of these. We'll look into what states are doing that and what else we can do.

So thank you, Mr. Chairman.

Senator SULLIVAN. Thank you, Senator Cantwell.

Senator Peters had a follow-up question.

Senator PETERS. Thank you, Mr. Chairman.

Just a comment I wanted to mention to Ms. Wallace, because you talked about fishing gear that gets cut loose or lost or whatever it may be floating around the ocean. I actually had an opportunity to at least see a video of some courageous folks from NOAA out in Monterey Bay, California.

I was out there recently, and about a week before I was there, I know that they were dealing with a humpback whale who had swam through an abandoned net that was wrapped all around the whale. The whale was struggling, was not going to survive, and folks from NOAA actually went out there in a small boat—went out there and hooked up to the whale—it was like a Nantucket sleigh ride from the old days—and cut the net off of the whale and set the whale free so it was able to live, and then was able to recover that net.

But I think the American public needs to know that NOAA is truly a hands-on agency that goes out there and is saving marine mammals as well as other work. So I wanted to thank you and all of your colleagues at NOAA for what you do every day.

Senator SULLIVAN. Dr. Wallace, I had a follow-up that I wanted to ask you about, and I know that you've done a lot of work on this issue. It's a particularly challenging issue, but it deals with remote areas in our country in terms of marine debris cleanup. And I agree with kind of the theme of the panel and the witnesses and some of the senators' questions. I mean, I think we clearly need to get to prevention as the key, but cleanup is also important.

There are areas, as you know, in Alaska that are extremely difficult to collect marine debris from that have literally tons of debris on some of our shores. The Gulf of Alaska Keeper, an Alaskan nonprofit that NOAA has worked with, collected and transported over 1 million pounds of marine debris from remote Alaska beaches in 2015 alone, using helicopters, barges, other ships with only a small crew of dedicated volunteers.

So what additional resources does your program require—or not just resources, but ideas on trying to get to some of these remote cleanup areas? Obviously, in Alaska, it's the most extreme cases, but I'm sure it exists in Michigan and other parts of the country, and this is a challenge for all of us.

Ms. WALLACE. Remote areas are an incredible challenge. That specific effort that the Gulf of Alaska Keeper led in 2015 was logistically amazing. You know, the fact that they were able to helicopter debris off these remote beaches, get them onto a barge, and then have that barge go down to Seattle really, I think, showcased exactly some of those challenges. We're also working with Sitka Sound Science Center in some very remote Bering Sea communities to remove debris that is most likely not being generated by those communities. It's washing ashore from offshore.

So I think it really does become just leaning on those partners that have that technical expertise and providing the funding that they need. So a lot of those partners have received funding through our competitive grants, and a lot of times, for the areas that are more remote, it costs more, and they get the higher grants, you know, and that's part of it.

But you're absolutely right. Removal has immediate ecosystem benefits, economic benefits. It's something we're going to keep doing.

Senator SULLIVAN. Just one final question related to that. How do we—you know, NOAA is doing a great job, and we're all complimenting you. Our bill looks to reinforce and expand your efforts. But how do we empower these organizations that are on the ground that are literally the front lines, like Gulf of Alaska Keeper and many, many others that Senator Peters mentioned, even some of the classroom activities? How do we work to further partner, but empower them to be able to effectively do this in a more creative way?

Ms. WALLACE. Well, I think one of the things we've been very proud of is that a lot of our partners get funding from us to get a project started, and then they actually make that project sustainable by finding funding elsewhere or, you know, thinking about innovative solutions.

So one of the things we're doing right now that's kind of a new, interesting idea is in Dutch Harbor, looking at collecting fishing nets that have been accumulating there forever, but looking at public-private partnerships, so working with Matson and Trident to actually collect the gear, truck it down to Seattle, and then actually sending it to Denmark to be recycled. I think that's one of the things we have to keep thinking about, is how do we get creative with the resources we have and the partners that are interested and have resources to give.

Senator SULLIVAN. Great. Well, again, we'll continue to work on that, and I appreciate your efforts in that regard.

I think we have a couple of other senators who are interested in asking the panel some additional questions.

Senator Blumenthal.

STATEMENT OF HON. RICHARD BLUMENTHAL, U.S. SENATOR FROM CONNECTICUT

Senator BLUMENTHAL. Thanks, Mr. Chairman.

I want to ask a question about cruise ships. We all know that cruise ships are a potential source of debris and waste. Let me ask you when cruise ships sail along the coast of the United States and out to sea, do you think that the current laws are sufficient to protect against the kinds of pollution they can cause, the current treaties and rules?

Ms. WALLACE. Well, cruise ships and all ships are subject to MARPOL Annex V, so they are not allowed to dump waste, specifically plastic waste or household waste, paper waste, in all areas. So the laws are there. I think the question becomes an enforcement issue, and that would be a question for our colleagues at the Coast Guard. But the laws are in place, and we are subject to those laws.

Senator BLUMENTHAL. Well, on enforcement, can you make some suggestions for how either the rules can be made more enforceable or what can be done to ensure greater enforcement?

Ms. WALLACE. Well, I think, again, I probably would want to defer to my colleagues at the Coast Guard since they are the lead for enforcement. I think in any case, certainly, education about the laws that do exist and really requiring our partners in all industries to be able to follow those are very important. But I think that may be a Coast Guard question to follow up on on the specific enforcement that they do with cruise ships.

Senator BLUMENTHAL. Mr. Balton?

Mr. BALTON. I'm not an expert on the regulation of cruise ships, but I can tell you this, that the cruise line industry has proven itself willing in the past to work with our government to use the cruises themselves as ways to educate the people on it about the marine environment, including about marine pollution issues, including from the ships themselves. So one other idea that might be worth pursuing is partnerships with CLIA and other cruise line industry associations to actually advance awareness of marine pollution problems.

Senator BLUMENTHAL. Are there specific efforts at education that you think should be undertaken?

Mr. BALTON. So another place where people have the best interest in keeping the marine environment pristine are the coastal resort communities and the big hotels. And, once again, you can enlist these partners to try to educate their consumers, the people who come to these places, on the importance of limiting trash.

Senator BLUMENTHAL. When you talk about education, do you mean education of passengers on the cruise ships or education of the managers and owners of the cruise ships?

Mr. BALTON. I would say both.

Senator BLUMENTHAL. But maybe you can tell me how passengers on a cruise ship—I realize they may toss stuff overboard, but the major source of contamination is from the waste emanating from the cruise ships, correct?

Mr. BALTON. Yes, so——

Senator BLUMENTHAL. So, really, when you talk about education, isn't the best means of education deterrence, in other words, enforcement?

Mr. BALTON. Yes, sir. That makes sense.

Senator BLUMENTHAL. So that brings us back to enforcement. Do you have any opinions on enforcement? Is there sufficient enforcement?

Mr. BALTON. Again, you should probably ask that question of somebody who is involved in enforcement of those laws, and that would principally be the Coast Guard, and also some colleagues in the Department of Justice involved in environmental enforcement issues of this kind.

Senator BLUMENTHAL. Thank you, Mr. Chairman.

Senator SULLIVAN. Senator Markey.

STATEMENT OF HON. EDWARD MARKEY, U.S. SENATOR FROM MASSACHUSETTS

Senator MARKEY. Thank you, Mr. Chairman, very much. Mr. Chairman, President Kennedy was right when he once said at the shores of the Atlantic Ocean that all of us have in our veins the exact same percentage of salt in our blood that exists in the ocean, and, therefore, we have salt in our blood and our sweat and in our tears. We are tied to the ocean, and when we go back to the sea, whether it is to sail or to watch it, we are going back from whence we came.

The Atlantic Ocean, Mr. Chairman, is a natural wonder. President Kennedy is correct. And it is also an economic engine supporting hundreds of thousands of jobs in key industries such as fishing and tourism. Fishing off of the East Coast states produces roughly $1.75 billion in direct value for those states and more than $4 billion in total economic activity each year. Tourism on the East Coast draws visitors to our beaches and our coastlines. It generates hundreds of billions of dollars in additional economic activity and supports an estimated 800,000 jobs.

Marine debris, which can range from larger items like plastic bags, water bottles, or other pieces of trash to microscopic plastic particles is a threat to this vital oceanic wonder and also to the industries in New England and other East Coast states that have sustained families in their employment for generations.

During the international coastal cleanup days in the fall of 2016, 2,500 volunteers in Massachusetts collected over 13,000 pounds of marine debris on 164 miles of Massachusetts' beaches and waterways. But this is a tiny amount compared to the estimated 8 million metric tons of plastic that makes its way into the ocean each year.

Ms. Wallace, how can this massive amount of marine debris harm not only our marine life and environment but also industries like the fishing industry of Massachusetts?

Ms. WALLACE. Marine debris can have a big economic impact both on—from a tourism standpoint, but also from a fishing standpoint. So one of the things that NOAA did a few years ago was do a comprehensive study looking at the economic impact of derelict crab pots in Chesapeake Bay. We found that if you remove targeted areas where there are a lot of traps that accumulate all at once, you can actually have an impact of 38 million pounds of crab harvest, which equates to $33 million. That's annually.

We have done similar work in Massachusetts with the lobster fisheries. So we've worked with the Department of Marine Fisheries to look at how many lobster are actually caught in lost fishing gear, and it's substantial. So I think looking at how we can look to prevent derelict fishing gear from being lost—but a lot of times, you really can't prevent it. So if we know where there are areas that we can actually remove to have that biggest impact is what we want to do, because these are really big numbers.

Senator MARKEY. Thank you. So what are the impacts of marine debris on fish stocks? Does it impact their ability to reproduce? Does it make them more susceptible to disease or other environmental stress? How else does it harm that fishing stock?

Ms. WALLACE. Well, fishing gear is extremely efficient at catching fish or crabs or lobster, and when it's lost, it will continue to do so for years. We found, even in Massachusetts, where lobster pots can continue to fish for decades. So what we want to be able to do is minimize that, because that's a huge, huge natural resource impact and also an economic impact on fishermen.

Senator MARKEY. So the New England Aquarium has been participating in a campaign called "In Our Hands," which is encouraging the public to choose alternatives over single use plastic. Would more organically based plastics help reduce marine debris? And how can we take this model to encourage using less single use plastic on a larger scale?

Ms. WALLACE. I think materials that are made of natural items obviously will degrade quickly in the environment, and so that's something we should look at. Biodegradable plastics can be a little bit of a misnomer, because they may not ever fully degrade in ocean conditions, and we don't want to give people the license to be able to toss that product, if they think it's biodegradable, into the ocean. So I think we have to be careful about looking for alternative materials—certainly something that will be important in solving the problem.

Senator MARKEY. Great. And as the ranking member on the Senate Foreign Relations Subcommittee on Near Eastern and South and Central Asian Affairs, I'm curious, Mr. Balton, about your work in East Asia. Your testimony discusses the State Department's efforts to work with rapidly developing Asian economies to reduce marine debris, especially micro plastics. International cooperation, especially with developing economies in Asia, is essential to reducing the amount of waste in our ocean.

How does marine debris from Asia impact our environment and industries here in the United States?

Mr. BALTON. Mostly because the trash that is dumped in the ocean there or makes its way into the ocean there arrives on our shores in Hawaii and Alaska and the West Coast. But we have found some venues in which to engage with the Asian producers of marine debris. I was talking earlier in the hearing about our efforts to use the Asia-Pacific Economic Cooperation forum to strengthen waste management capabilities in these Asian states. We're trying to support Indonesia, which has articulated a goal of reducing its marine debris pollution by 70 percent by 2025.

Senator MARKEY. Can I just ask you on that issue of Indonesia's goal of reducing it by 70 percent by 2025?

Mr. BALTON. Yes.

Senator MARKEY. What is the role the State Department is playing, our government is playing, in helping the Indonesian government to accomplish that goal?

Mr. BALTON. We're trying to connect people in Indonesia with the experts in the United States who know about this. For example, we sponsored Dr. Jambeck from the University of Georgia, one of our leading experts, to go to Indonesia to work with the officials there and to raise awareness of this problem. So we see ourselves as a facilitator of these types of activities.

Senator MARKEY. Great. Thank you.

Mr. Chairman, Mr. Ranking Member, thank you so much for holding this very important hearing. I just think it spotlights something that is critical for us to deal with on a bipartisan basis. Thank you.

Senator SULLIVAN. Thank you, Senator Markey, and we appreciate your strong support on this.

I also just want to mention—Ambassador Balton, you talked about partnerships. I think—we've been talking about how this bill has broad-based bipartisan support. It also has strong, strong support across different sectors of advocacy groups, environmental groups, industry groups, and in that regard, I'd like to submit for the record the statement for the record by the American Chemistry Council, and I'm going to submit that for the record, without objection.

[The information referred to follows:]

PREPARED STATEMENT OF THE AMERICAN CHEMISTRY COUNCIL

Thank you Chairman Sullivan and Ranking Member Peters for your leadership in holding this important hearing. The American Chemistry Council represents the leading companies engaged in the business of chemistry. ACC member companies apply the science of chemistry to create innovative products that make people's lives better, healthier and safer, and to help solve society's greatest challenges.

The business of chemistry is a $768 billion enterprise and a key element of the Nation's economy. Over 26 percent of U.S. GDP is generated from industries that rely on chemistry, ranging from agriculture to oil and gas production, from semiconductors and electronics to packaging and vehicles, and from pharmaceuticals to residential and commercial energy-efficient building products. Our industry directly employs over 810,000 Americans in high-paying jobs, and each of those jobs supports an additional 6.3 American jobs in other manufacturing industries. Every day, the products of chemistry, including many plastics, improve our quality of life while contributing to sustainability by allowing us to do more with less. Today's chemistry and plastics help to reduce energy use, lower greenhouse gas emissions, and significantly reduce waste.

ACC welcomed the recent introduction of S. 756, the "Saving Our Seas Act," by Senators Sullivan, Whitehouse, Peters, Booker, Inhofe, Murkowski and Tillis, and appreciates the opportunity to submit a statement for the record for today's Senate Commerce Subcommittee on Oceans, Atmosphere, Fisheries and Coast Guard hearing entitled "Marine Debris: Efforts on Marine Debris in the Oceans and Great Lakes." We strongly support reauthorization of NOAA's Marine Debris Program and the Act's emphasis on promoting international action to reduce marine debris.

Despite ocean health becoming a global priority, every year more and more trash enters the world's waterways. Experts agree that to stem the tide of marine litter, we must prevent land-based trash from reaching our oceans in the first place. We must do so urgently, with an initial focus on parts of the world where waste management systems currently are lacking. This includes reducing waste, improving collection and sortation, and expanding access to the latest recycling and recovery technologies. A study by Jambeck *et al.,* 2015, published in *Science* magazine estimates that 60 percent of the world's trash comes from just five rapidly developing countries (China, Indonesia, the Philippines, Vietnam and Sri Lanka).[i] ACC fully supports several features in this much needed bill, including provisions to further study land-based waste management solutions and causes of marine debris, and increased investment and technical assistance to help expand waste management systems in rapidly industrializing nations.

Plastics makers currently have *more than 260 projects* underway around the globe to combat marine litter. Our combined efforts to research and prevent marine debris under the *"Declaration of the Global Plastics Industry for Solutions on Marine Litter,"* have grown each year since 2011, when it was launched. Signed by 70 plastics associations in 35 countries, the declaration focuses on education, public policy, best practices, plastics recycling and recovery, plastic pellet containment, and research.

In addition, we are working with leaders in regions where plastics leakage into the ocean is the highest to ensure that waste management systems are a priority and to catalyze investment in those systems. And we are working with the United Nations to provide technical expertise and a range of commitments under the Global Partnership on Marine Litter.

People around the world rely on plastics in innumerable ways. Durable and lightweight, plastics provide important societal benefits including energy and resource savings, food waste prevention, improved healthcare and consumer protection. But when plastics are improperly managed, their full sustainability benefits aren't realized. Solutions require the cooperation of industry, civil society and other stakeholders to effect meaningful change.

Companies that use chemistry to make plastics for a range of packaging and consumer goods that help us to live more sustainably applaud the Saving Our Seas Act, and we are fully committed to the goal of keeping waste of all kinds out of our ocean. We look forward to continuing our work with the Congress, its Oceans Caucuses, NOAA, the State Department and all other stakeholders to enhance international engagement in improving land-based waste management practices to address marine debris, and the bill's sponsors to bring this legislation to the President's desk.

Senator SULLIVAN. The first panel is excused. I thought that was an excellent, excellent discussion of this important issue. We want to thank you for your work on this, and we look forward to continuing to work with you on this important issue.

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[i] Jenna R. Jambeck *et al.,* Plastic Waste Inputs from Land into the Ocean. *Science,* 13 Feb. 2015, Vol. 347, Issue 6223, pp. 768–771, *http://science.sciencemag.org/content/347/6223/768*

I would like to call up Dr. Melissa Duhaime, Assistant Professor from the University of Michigan, to lead our second panel.

Dr. Duhaime, welcome. Thank you for listening to the first panel, and we look forward to hearing your testimony. I believe that we will also have Senator Whitehouse joining you to testify here in a few minutes. But we'd like you to begin. So, please, welcome. Thank you.

STATEMENT OF MELISSA B. DUHAIME, PH.D., ASSISTANT PROFESSOR, DEPARTMENT OF ECOLOGY AND EVOLUTIONARY BIOLOGY, UNIVERSITY OF MICHIGAN

Dr. DUHAIME. Good morning. I thank Chairman Sullivan and my Michigan senator, Ranking Member Peters, and the Subcommittee members for inviting me to today's hearing. As a representative of the research community, I appreciate being at this table and part of these discussions.

My name is Melissa Duhaime, and I'm a Professor at the University of Michigan in the Department of Ecology and Evolutionary Biology. I studied at Cornell University, and I hold a Doctorate from the Max Planck Institute for Marine Microbiology.

I've worked in ocean and freshwater sciences for over a decade, and I've sampled their studied plastics around the globe, but most extensively in the Great Lakes over the last five years. In that time, we've learned that plastic pollutants are widely present in the Great Lakes and impact food supplies of aquatic animals but with unknown consequences to human health.

A study out last week reported that almost 80 percent of plastic ever produced still remains in landfills or dispersed in the environment today. I've heard a lot of analogies today, so I'll add one more to that. That represents 10 times the biomass of humans on this planet. So for every one of us in here, there are 10 more of us out there in plastic. Each year, 8 million tons of plastic find its way into our oceans. These numbers will continue to rise as the global production of plastic continues to increase exponentially, as we've heard a lot about today.

These trends are no different in freshwater. While most research has focused on the distribution and impacts of marine litter, most plastic pollution originates on land. Fresh water bodies serve as conduits for the transport of this plastic to the oceans, and humans live in closer contact with freshwater. Ninety percent of the world's population live only six miles from a freshwater body.

As the largest freshwater system on the planet, the Great Lakes hold one-fifth of the world's surface freshwater, and these are arguably one of the most valuable national security assets. In 2014, my lab led the largest survey to date of Great Lakes plastic pollution. We collected and counted surface plastic as small as one-tenth of a millimeter from over 100 samples.

We found plastic at every site. The sample with the highest concentration of plastic from the Detroit River contained almost 2 million plastics per square kilometer. That's four times higher than yet reported in the surface of the Great Lakes and among the highest ever reported in nature. The highest concentrations of plastics were found near Great Lakes cities, in river plumes, directly at the output of waste water treatment plants, and following storm events.

As with all plastic pollution, the smallest plastics dominated our samples. Given this trend, new analytical techniques are needed to quantify with higher confidence and higher throughput the micro and especially nano-sized plastics, of which we know near nothing about but whose health risks would be the highest. Nanoplastics have the potential to pass cell membranes, delivering toxins and directly interfering with metabolic pathways.

In ongoing laboratory studies at the University of Michigan, Lake Michigan Quagga mussels and Chironomid worms consume nano-sized plastic, mistaking them for food. These organisms, the mussels and these worms, are central to the Great Lakes food web. The worms are a food source for all the foraging fish, which are then consumed by the greater fish-eating fishes, such as salmon, trout, bass, and walleye, and later by humans.

In the water, these plastics serve as sponges of persistent organic pollutants. Two of these toxins, which are known carcinogens that can also interfere with reproduction, PAHs and PCBs, were detected on plastic from Lake Sinclair, the Detroit River, and near the Cleveland Waste Water Treatment Plant output. Also, antibiotics, herbicides, fungicides, and insecticides have been detected on plastic in Lake Erie. The implications of these findings, particularly for the living creatures that eat the plastics, have not yet been explored.

So, in summary, the basic research has shown that plastic is everywhere. It's in all oceans on the planet, in the Great Lakes, in remote alpine lakes, in beer and fish sold for human consumption, and it's near certain that humans are consuming plastic. In the wake of these discoveries, the U.N. has declared plastic pollution among the most critical emerging environmental issues of our time, and the scientific consensus is that plastic pollution must be reduced to avoid risk of irreversible ecosystem harm.

As of today, the direct human health consequences of plastic are unknown. Continued basic research really is central to our ability to define these environmental risks and the economic and public health impacts of plastic pollution. I look forward to sharing future findings with you all and continuing to be a resource to the Committee.

I thank you, and I look forward to questions.

[The prepared statement of Dr. Duhaime follows:]

PREPARED STATEMENT OF MELISSA B. DUHAIME, PH.D., ASSISTANT PROFESSOR, DEPARTMENT OF ECOLOGY AND EVOLUTIONARY BIOLOGY, UNIVERSITY OF MICHIGAN

Disclaimer

The findings and perspectives presented in this testimony represent the author's own professional assessment as an independent academic researcher. They should not be taken to reflect the views of the University of Michigan, the author's past affiliations, or funders present or past.

Summary Statement

I wish to thank Chairman Sullivan, and my Michigan Senator, Ranking Member Peters, as well as the members of the Subcommittee for inviting me to today's hearing. As a representative of the basic research community, I appreciate being at this table and part of these discussions.

My name is Melissa Duhaime and I am an assistant professor at the University of Michigan in the Department of Ecology and Evolutionary Biology. I studied biology at Cornell University and hold a doctorate from the Max Planck Institute for Marine Microbiology in Germany.

I have worked in ocean and freshwater sciences for over a decade, studying plastics across the world's oceans, and most extensively in the Great Lakes, where I began my career in Michigan 5 years ago—in fact, that time marked the very inception of this young research field.

Plastic hit the consumer market after WWII, when the economics of this cheap good and the convenience of a throw away culture took off. 60 percent of plastic ever produced—5 billion tons—still remains in landfills or dispersed in the environment today. This is equivalent to 10 times the biomass of all humans on Earth. For each of us in this room, there are 10 of us made of plastic out there. Each year, 5–13 million tons of plastic enter the oceans. These numbers will continue to rise the global production of plastic goods continues to increase exponentially. The trends are no different in the Great Lakes.

In 2014, we carried out the largest survey to date of Great Lakes surface plastic pollution, traversing Lakes Superior, Huron, St. Clair, and Erie. We collected surface-floating plastic down to one-tenth of a millimeter. We found plastic at every site sampled. The sample with the highest total concentration of plastic (in the Detroit River) contained almost 2 million particles per km, 4-times higher than yet reported in the surface of the Great Lakes.

The highest concentrations of plastic were found near populated Great Lakes cities, in river plumes, directly at the effluent of wastewater treatment plants, and following storm events.

As with all plastic pollution, the smallest plastics dominated all samples. Given this trend, it is essential that more attention be paid to the smallest size classes of plastic, especially the nanoscale, of which we know near-nothing about, but whose health risks will be highest.

The vast majority of plastic detected with secondary plastic fragments, broken down from larger pieces—not the microbeads reported to dominate in the first study of Great Lakes plastic.

Plastic floating in water serves as sponges of toxic persistent organic pollutants (or "POPs") that are consumed when plastics are. Two carcinogens, polyaromatic hydrocarbons (PAHs) and polychlorinated bisphenyls (PCBs), were detected on plastic from Lake St Clair, the Detroit River plume, and Cleveland WWTP effluent. Also, antibiotics, herbicides, fungicides, and insecticides have been detected on plastic in Lake Erie. The implications of these of findings have not yet been explored.

In a U–M study of fish and mussels collected from the Great Lakes, roughly one-quarter of all Great Lakes fishes and one-third of bivalves examined contained plastic fibers in their stomachs.

In laboratory studies, Lake Michigan Quagga mussels and Chironomid worms consume nano-sized plastic, mistaking them for food. These organisms, especially the worms, are central to the Great Lakes food web. They are a food source for all the foraging fish, which are then consumed by greater "fish-eating fishes", such as salmon, trout, bass, and walleye.

Research is needed to define the effects of consumption and to determine the economic and public health impacts of plastic pollution in the Great Lakes.

In summary, basic research has shown the plastic is everywhere, in all oceans on the planet, remote alpine lakes, in the Great Lakes, and in beer and fish sold for human consumption. It is near certain that humans are consuming plastic.

In the wake of these discoveries, the United Nations has declared plastic pollution among the most critical emerging environmental issues of our time. The scientific consensus is that plastic pollution must be reduced to avoid the risk of irreversible ecosystem harm.

The direct human health consequences of plastic pollution are unknown, but this is the essential frontier of basic research.

As put by environmental toxicologist, David Sedlak, "Although we are all responsible for microplastics in the environment, getting the entire world to rethink the way it uses synthetic polymers would be a long, arduous process requiring compelling evidence of severe environmental risks."

Basic research is critical to our ability to understand the extent and implications of this issue. I look forward to sharing future findings with you and continuing to be a resource to the Committee. I look forward to your questions now and in the future. Thank you.

PLASTIC POLLUTION IN THE GREAT LAKES

I. Introduction

The accumulation of plastic debris in nature is "one of the most ubiquitous and long-lasting recent changes to the surface of our planet." [1] Since plastic hit the consumer markets in the 1950s, 60 percent of plastic produced—4.9 billion metric tons—still remains in landfills or is inadvertently dispersed in the environment.[a] That is 10 times more than the biomass of humans on the planet. Each year, *5–13 million tons of plastic find its way into our oceans.*[2] In the absence of mechanisms to incentivize improved waste management and behavior change, this number will continue to rise, reflecting the *exponentially increasing global production of plastic goods.*[3]

Aquatic organisms ingest plastic pollutants,[4,5] which results in energetic and fitness costs[6,7] and other morbid impacts.[8] Microscopic plastic is found in fish and shellfish sold for human consumption at seafood markets around the world, including in Europe[9] and in the U.S.[10] There is a high likelihood that humans are consuming this plastic. The health consequences of this are unknown.

In the wake of these discoveries, the *United Nations has declared plastic pollution among the most critical emerging environmental issues of our time.*[11] The scientific consensus is that plastic pollution must be reduced to avoid the risk of irreversible ecosystem harm.[12]

While most research has focused on the distribution and impacts of *marine* litter, most plastic pollution originates on land.[13] As such, *freshwater bodies serve as conduits for the transport of plastic litter to the ocean.* Humans live in close contact with freshwater. 90 percent of the world's population lives 6 miles from a freshwater body.[14]

Recently, *plastic has been documented in the Great Lakes at some of the highest concentrations seen on the planet.* Yet, too little is known about the fate of this plastic and its role in ecosystem dynamics to assess environmental risk and predict the impacts on one fifth of the world's surface freshwater and arguably one of our most valuable national security assets.

This discussion focuses on recent findings led by our team at the University of Michigan regarding plastic pollution in the Great Lakes. It (1) reports the quantification, distribution, and modeled transport of Great Lakes plastic debris, (2) describes the carcinogenic toxins that hitch a ride on Great Lakes plastic, (3) demonstrates that organisms central to the Great Lakes food web consume plastic, and (4) explores new frontiers in the detection of nano-sized plastic. The report concludes by highlighting recommendations for future research directions. These aim at addressing current knowledge gaps in our ability to assess environmental risks of this pervasive, persistent pollutant—in the Great Lakes and beyond.

II. Plastic Pollution In The Great Lakes

In 2014, we carried out the largest survey to date of Great Lakes surface plastic pollution, quantifying plastic in over 100 samples collected across Lakes Superior, Huron, St. Clair and Erie.[15] With funds from the University of Michigan Water Center and Erb Family foundation, as well as a generous donation of time, research vessel, and fuel by citizen scientist, David Brooks (resident of Chelsea, MI), we traversed these lakes and collected surface-floating plastic down to 100 µm—one-tenth of a millimeter, smaller than a period on this page.

We have *worked for four years with NOAA's Marine Debris Program to develop an Action Plan for the Great Lakes.* The Great Lakes plastic research community is incredibly collaborative and connected, in large part due to the organizing efforts of NOAA's Marine Debris Program in the region. I have worked with the International Joint Commission to establish recommendations on how to address the problem of plastic pollution in our Great Lakes. Our data have contributed to follow-up research programs and private funding, remediation action plans, and new knowledge disseminated to the public through outreach initiatives around the Great Lakes. Our work has been published in peer-reviewed journals[15-17] and key elements are summarized below.

A. Abundance and Distribution

While floating plastic bottles and bags, styrofoam coolers, straws, old tires, and cigarette butts disrupt our intrinsic connection with "pristine" natural spaces, most Great Lakes plastic is small, nearly invisible "microplastic" (<5 millimeters in size).

[a] *https://www.nytimes.com/2017/07/19/climate/plastic-pollution-study-science-advances.html?mcubz=0*

Figure 1. A calm and seemingly clean Lake Erie (left), photo credit, Melissa Freeland; particles collected following a storm event from the surface of Lake Erie at the Cleveland wastewater treatment plant effluent site (right), many of which proved to be "microplastic" (defined as plastic <5 mm in size).

What we collected in our field survey were not the pristine samples we had collected previously across the world's oceans, which consisted primarily of plastic and little else. Rather, with each surface trawl, we pulled up pounds and pounds of biomass—such as algae, insect larvae, sticks, and leaf litter. Enmeshed in this was microscale plastic trash (Figure 2).

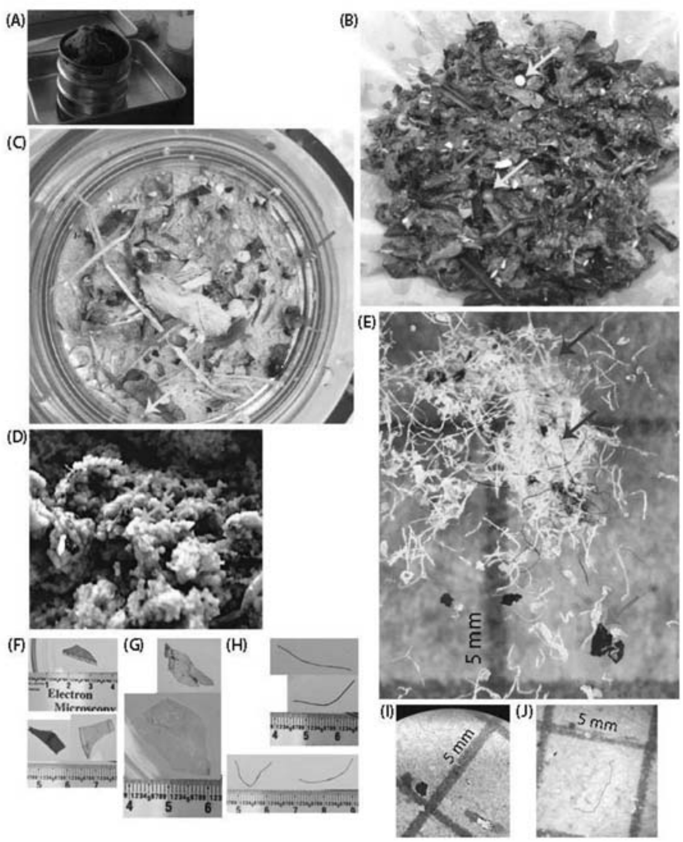

Figure 2. From [15]. Samples from Great Lakes plastic survey of 2014 at various stages of processing, including examples of different shape classes. Arrows indicate plastic amidst co-sampled nonplastic organic matter; blue: fragment, dark red: line, yellow: nurdles, cyan: sphere/bead,

brown: fiber. *(A)* Bulk sample directly upon retrieval from surface net on a stack of a series of sieves. This sample contained an abundance of algal biomass. *(B)* Bulk sample drying on a 53 µm mesh net. *(C)* Sample after enzymatic processing, which included an incubation in hydrogen peroxide that bleached much of the non-plastic organic matter. This bleaching aided in differentiating plastic (tended to retain color) from non-plastic (prone to bleaching) particles. *(D)* Examples of plastic of sphere class; zoomed in subset of sample in *(B)*. *(E)* Smallest size fraction (106–1,000 µm) after hydrogen peroxide treatment. Note colored plastic fibers (brown arrows) enmeshed in mass of natural fibers bleached white from hydrogen peroxide treatment. *(F–H)* Examples of plastic of fragment, film and line shape classes, respectively; ruler markings are in cm units. *(J,I)* Examples of plastic of paint chip and fiber shape classes, respectively; grid squares are in 5 mm units.

We found plastic at every site sampled in this Great Lakes study (Figure 3). The sample with the highest total concentration of plastic (in the Detroit River) contained almost 2 million particles km,$^{-2}$, a *4-fold higher concentration than yet reported in the surface of the Great Lakes.*[18,19]

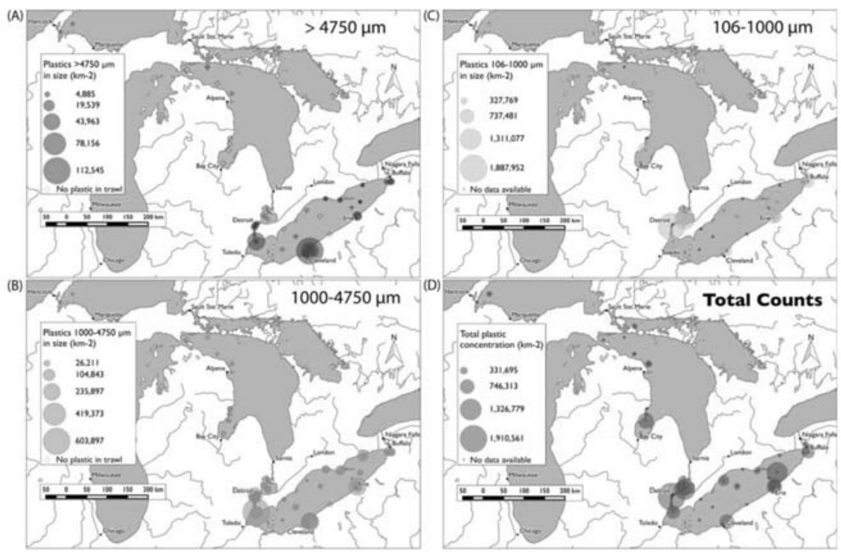

Figure 3. Maps of plastic concentrations across the lakes sampled; magnitude of concentration is depicted by size of circle around trawl location. Note, fiber counts are not included in these figures, as their quantification is error prone. *(A)* Mapped counts of plastic litter >4,750 µm. *(B)* Mapped counts of plastic litter 1,000–4,750 µm. *(C)* Mapped counts of plastic litter 106–1,000 µm. *(D)* Total mapped counts for the stations where all three size classes were quantified.

Across our Great Lakes study and in nearly all studies to date, the smallest plastics dominate. The vast majority of plastic counted was <1 mm in size (Figure 4A), regardless of water body or types of stations sampled. Smaller plastic particles stay at the water surface longer than larger particles of the same composition and shape[20,21] and are more readily consumed by smaller organisms in aquatic food webs.[22] The larger surface area to volume ratios of these small plastics increases their potential to deliver toxic chemicals (discussed below) to the organisms that consume them.[1,23] Given this trend, *it is essential that future studies document submillimeter (nanoscale) plastics and develop innovative high-throughput solutions to capture and quantify nanoscale plastics. The ecosystem risks of nanoscale plastics may be highest* due to subcellular effects[24]—but, due to technical limitations, they have yet to be identified or quantified in natural systems. We have begun addressing this issue (see section on Organismal Impacts, below).

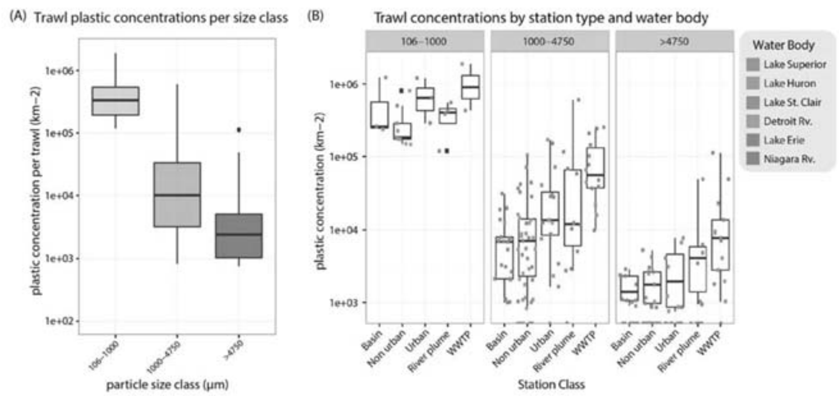

Figure 4. (A) Boxplots depicting the means and spreads of plastic counts by particle size class (from smallest to largest, left to right). *(B)* Boxplots depicting the means and spreads of plastic counts by size class, station type, and water body: Lake Superior, Lake Huron, Lake St. Clair, the Detroit River, Lake Erie, and the Niagara River.

The *highest concentrations of plastic were found near populated urban cities, in river plumes, directly at the effluent of wastewater treatment plants* (Figures 3–4), *and following storm events.* The Cleveland, OH, sample was collected at a WWTP effluent site immediately following a massive rainstorm (Figure 1, right panel; Figure 3A). We suspect we captured a combined sewage overflow event, whereby plastic in runoff that bypassed the treatment plant was delivered to the lake with no treatment.

Overall, these findings support previous reports of a correlation between plastic concentrations and proximity to urban centers in the Great Lakes.[25] Attributes that are likely to contribute to elevated plastic concentrations in urban vs. non-urban locales include higher population densities,[2] increased atmospheric inputs (including plastic; [26]), and increased areas of impervious substrate.[25] Increasing the degree of *pervious* substrate in watersheds, such as the *implementation of green infrastructure catchments, should be explored as an effective measure to capture plastic debris* in runoff and to reduce loads to waterways. As the number of storm events is expected to increase with a changing climate,[27] such innovations are timely to buffer preventatively our freshwater systems from being inundated with stormwater-delivered debris.

Most Great Lakes plastic appears to be "secondary microplastics" broken down from larger pieces of debris (Fig. 5). This counters the first report of plastic from the Great Lakes that reported the majority to be in the form of spherical plastic microbeads,[18] which have since been banned from rinse-off cosmetics.[28]

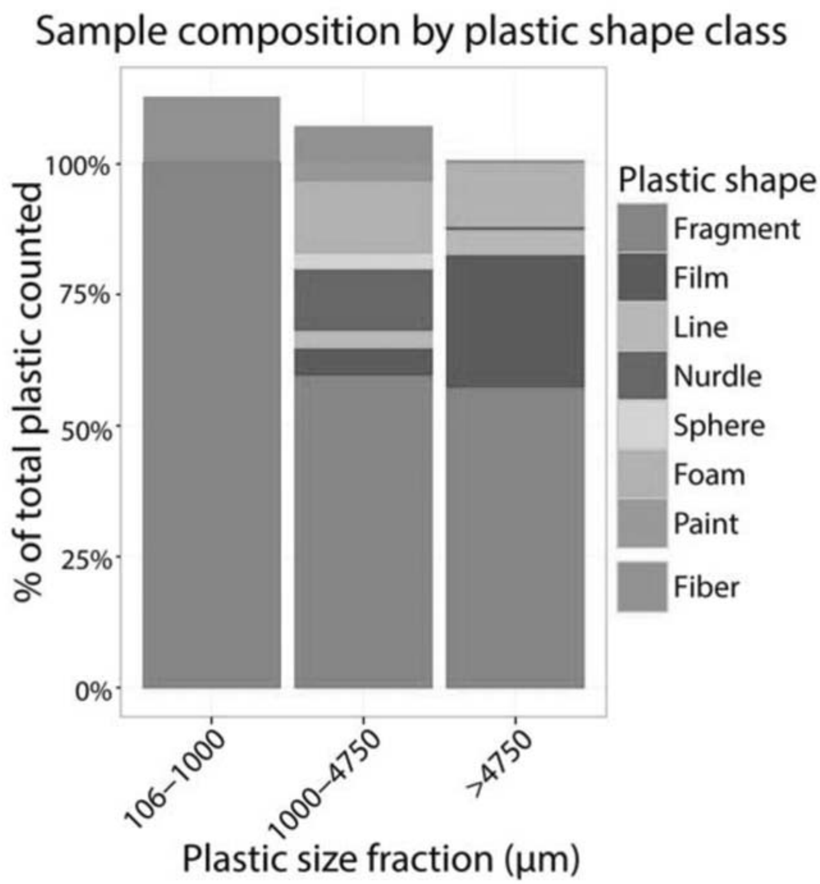

Figure 5. Stacked barplot depicting the relative abundances of different shape classes amongst plastic from each size class. The bar to 100 percent for each size class represent the relative abundance of different shape classes when fibers were not included in the total counts; the portion above 100 percent represents the relative abundance of fibers in the total counts.

Our Great Lakes study was the first survey of freshwater plastic litter to address variability in counts by conducting replicate trawls at each of 38 stations. With this replication, we were able to determine that the accuracy of a single trawl at one station was quite low. Repeated trawls at the same location can vary in precision by up to 3-fold. Evidence suggests that this variability is due to undersampling. In other words, to get reliable data, we must sample multiple times at each site and each sample must be larger.

Yet, across this field of research, replication is nearly never performed due to the massive investment that would be needed for data collection. Currently the most common method for quantification of plastic depends near-exclusively on visual sorting and counting.

Analytical approaches have been employed that rely on spectroscopic techniques (*e.g.,* fourier transform infrared spectroscopys—FTIR, Raman spectroscopy) to confirm whether particles are known synthetic polymers. But as of yet, these approaches are low-throughput and are limited by our inability to identify complex (often proprietary) mixtures of polymers and dyes outside the standard known polymer classes.

The *development of analytical techniques for high throughput, high confidence plastic counts is critically needed.* Such advancements will pave the way for accelerated data collection, down to nano-sized particle classes, and will drastically improve the reliability and value of future data generated.

B. Modeled Transport

In the absence of an inexpensive, rapid, and accurate method to quantify plastic debris on large temporal and spatial scales, hydrodynamic models were applied to predict the plastic distribution and transport of plastic in one of the Great Lakes, Lake Erie (D. Beletsky, R. Beletsky; U–M Cooperative Institute for Great Lakes Research; NOAA Great Lakes Environmental Research Labs; Ann Arbor, MI).

Our plastic transport model predicted habitats along the southern coast of Lake Erie to be most affected by plastic pollution (Figure 6).[15]

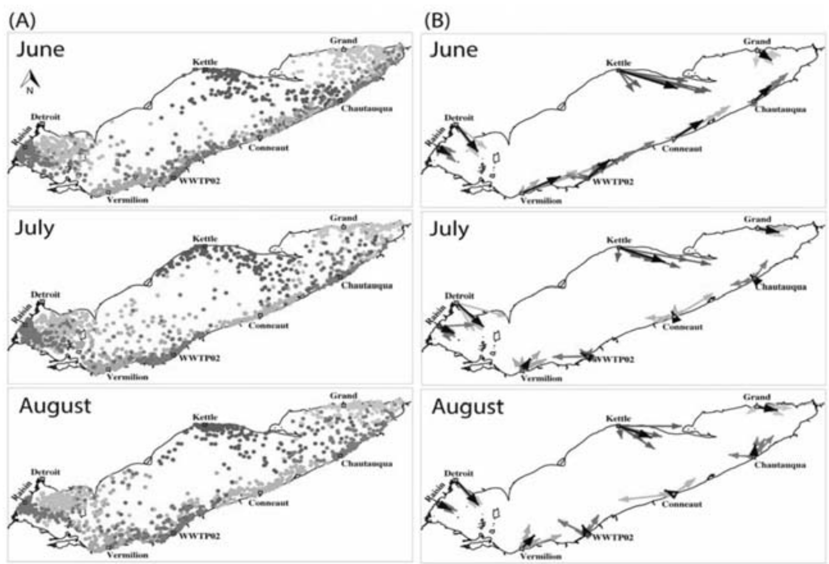

Figure 6. (A) The modeled distribution of neutrally buoyant particles in Lake Erie at the end of month-long simulated transport in June, July, and August for 6 years. For visual simplicity, 8 of the 29 sources (influents) are depicted: the Raisin Rv. (magenta), Detroit Rv. (cyan), Kettle Rv. (purple), Grand Rv. (turquoise), Chautauqua Rv. (blue), Conneaut Rv. (orange), Cleveland WWTP (red), and Vermillion Rv. (green). *(B)* Mean transport vectors summarizing the positions of all particles at the end of month at each of the same eight representative sources (similarly colored coded). The six vectors per source represent mean transport for each of the 6 years. The 6-year mean vector is shown in black at each input.

In most months, rather than moving offshore, the model predicted longshore transport from coastal sources (Figure 6A). This *model indicates that future plastic pollution mitigation and management efforts in Lake Erie should focus on its southern shore and downstream of urbanized areas.* Extending this plastic transport model to the other four Great Lakes will similarly inform future efforts across this critical watershed.

C. Plastic-adsorbed Toxins

Plastic floating in water serve as veritable sponges of toxic persistent organic pollutants (POPs). Plastic additives leach from plastics as they degrade (*e.g.,* phthalates, BPA), induce toxic effects in aquatic organisms,[29] and bioaccumulate in plastic-ingesting organisms [4,7] with unknown consequences.

Two carcinogens, polyaromatic hydrocarbons (PAHs) and polychlorinated bisphenyls (PCBs), were detected on plastic samples collected from Lake St Clair, the Detroit River plume, and Cleveland WWTP effluent. PAHs were detected on plastics at concentrations ranging from 3500–17,000 ng/g; PCBs ranged from 4–99 ng/g (L Rios Mendoza; U–W Superior). The levels of PAHs measured on individual pieces of surface-floating plastic are 10 to 100 times higher than concentrations considered hazardous to sediment-dwelling organisms (6–150 ng/g[b]). Concentrations of PCBs measured on plastic are on the order measured in plankton in the Great Lakes.[Hornbuckle 2006] Both PAHs and PCBs bioaccumulate with the potential to biomagnify, meaning that due to their persistence in the environment and the inability

[b] *http://www.ukmarinesac.org.uk/activities/water-quality/wq8_40.htm*

of some organisms to metabolize the compounds, toxins can be passed to consumers in prey. Biomagnification happens across the food web for PCBs and only in low levels (algae and lower invertebrates) for PAHs. This results in concentrations of PCBs in apex predators at the top of the food chain higher than would be expected based on transfer from water alone.

Beyond the suite of POP toxins most plastic researchers screen for, researchers at the University of Michigan conducted the first survey of non-target toxins on plastics in the Great Lakes. *Antibiotics, herbicides, fungicides, and insecticides were identified on plastic in Lake Erie* (K Wigginton; U–M Civil and Environmental Engineering). The implications of these of findings have not yet been explored.

D. Organismal and Food Web Impacts

In a study of fish and mussels collected from the Great lakes, roughly one-quarter of all Great Lakes fishes and one-third of bivalves examined contained plastic fibers in their stomach contents (Larissa Sano, University of Michigan). Of the particles documented in the fishes, 100 percent were fibers. *A systematic survey of the incidence and population-level impacts of consumption of micro-and nanoplastics across the Great Lakes biota is needed.*

In collaboration with the Banaszak Holl Lab at the University of Michigan and the San Francisco Estuary Institute, with funds from the Gordon and Betty Moore Foundation and NSF–REU program, we have *developed and applied a new method to identify nanoscale plastic pollution* (Figure 7). This method combines atomic force microscopy (AFM) with infrared spectroscopy (IR) create infrared spectra of individual micro-and nanoplastics at the individual particle-level.

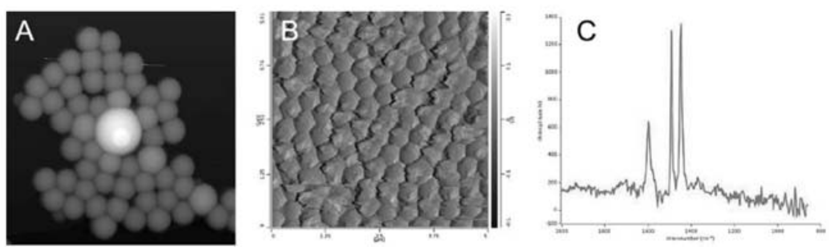

Figure 7. (A) A monolayer of beads visualized using AFM. (B) Red dot indicates polystyrene bead from which spectrum generated in panel C was obtained. (C) IR spectrum indicating characteristic peaks of polystyrene at 1452 cm^{-1} and 1492 cm^{-1}. Data generated by Rachel Merzel, Banaszak Holl Lab (University of Michigan).

We have confirmed the uptake of nanoplastics by Great Lakes filter feeders, a first step in defining the impact of their consumption on the Great Lakes food web.

Quagga mussels collected from Lake Michigan were fed fluorescently dyed nanoplastics the same size and at roughly the same concentration as their algal food source (0.01 and 0.1 picomolar; Figure 8). The mussels ingested the nanoplastic in a manner analogous to food consumption. The patterns observed in the gill tissue (Figure 8C) follow those of normal food accumulation, moving from the gills to the intestines. Mussels have internal mechanisms to reject particles they do not intend to digest. These data suggest the *nanoplastics are not rejected by Lake Michigan Quagga mussels, but rather are mistaken for food.* When smaller beads were used (200 nm), they also were observed in the gills and digestive tract. The Banaszak Holl lab will confirm whether such small beads are able to pass directly across cell membranes, which would pose a more lethal threat.

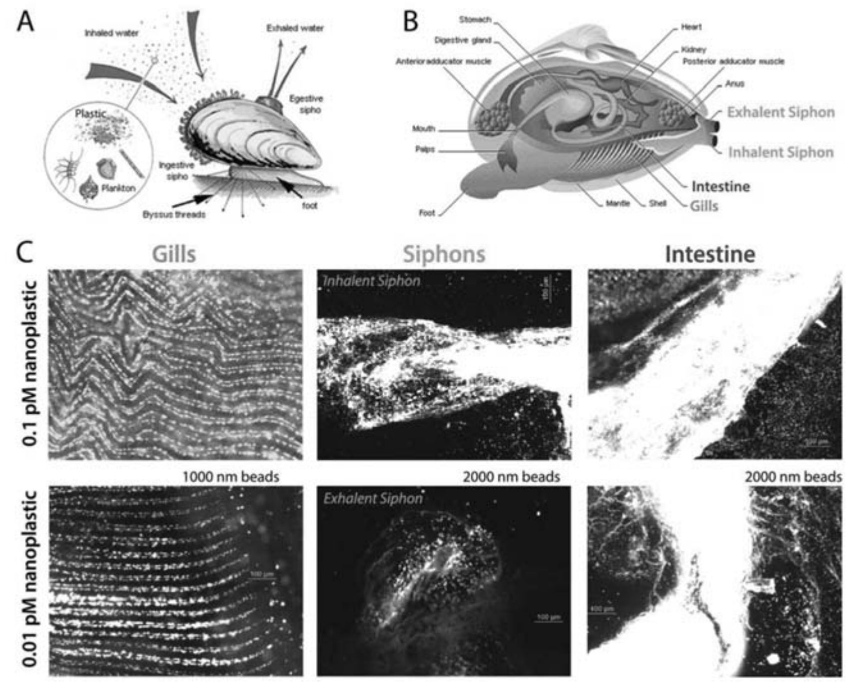

Figure 8. (A) Image[c] of mussel filter feeding. Plastic and food (plankton) enter the mussel in inhaled water, waste exits in exhaled water. (B) Diagram[d] of mussel anatomy. Note gills, inhalent and exhalent siphons, and intestines. (C) Microscopy images of internal structures of Lake Michigan Quagga mussels after being fed their algal food source along with 0.1 picomolar (top) and 0.01 picomolar (bottom) fluorescent plastic spheres. Plastic particles are the bright white elements of the image. Images from Lauren Purser, Banaszak Holl Lab (University of Michigan, NSF–REU). Recently collected data from currently unpublished work.

Benthic *Chironomid worms that live in the Lake Michigan sediment with the mussels also ingest the 200 nm and 2000 nm nanoplastics* and at concentrations greater than those observed in the mussels (Figure 9).

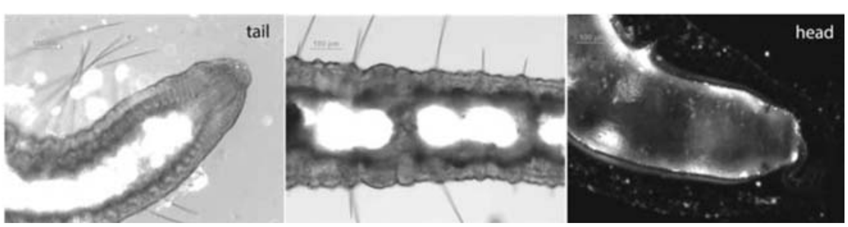

Figure 9. (A) Microscopy images of Lake Michigan Chironomid worms in tank with Quagga mussels exposed to fluorescent plastic spheres. Plastic particles are the bright white elements of the image. Images from Lauren Purser, Banaszak Holl Lab (University of Michigan, NSF–REU). Recently collected data from currently unpublished work.

Chironomids, as well as Quagga mussels, are central to the Lake Michigan food web. They are consumed by all foraging fish that live in the lake (Figure 10)—and, in fact, most of the Great Lakes. Trophic transfer of consumer plastic has been confirmed.[31] As such, owing to their resistance to degradation, *nanoplastics consumed by these Great Lakes mussels and worms have the potential to move up the Great Lakes food web to the high value piscivorian fishes ("fish-eating fishes"), such as salmon, trout, bass, and walleye* (Figure 10).

[c] *http://www.molluscs.at/bivalvia/index.html?/bivalvia/main.html*
[d] *https://7salemanimalkingdom.wikispaces.com/Mollusks*

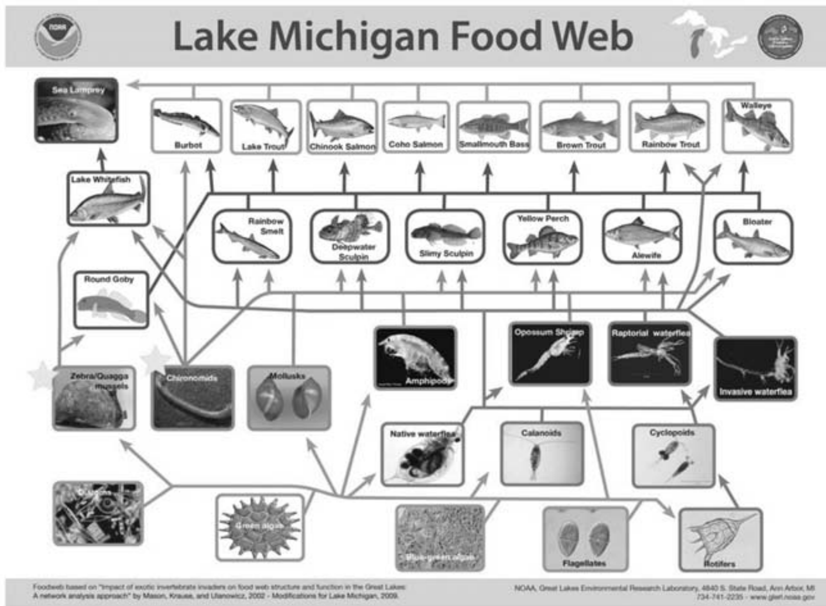

Figure 10. Lake Michigan food web. Prepared by NOAA Great Lakes Environmental Research Laboratory.[e] Note the yellow stars indicating the Quagga mussels and Chironomid worms highlighted in the research shared above.

Other researchers have confirmed that *ingesting plastic in place of food results in reduced biomass;* plastic lacks nutrients for growth.[7] Ingested plastic nanoparticles have led to *changed foraging behavior and organ function in fish.*[32] It is yet to be confirmed what the effects of plastic consumption are on the population-level fitness of Great Lakes fishes. This work is needed to determine the economic and public health impacts of plastic pollution in the Great Lakes.

III. Conclusion

As the largest freshwater system on the planet, the Great Lakes hold 20 percent of the world's surface freshwater. With this study, plastic pollution has now been documented down to the smallest size class reported to date. This led to the discovery of plastic concentrations up to *2 million particles per square kilometer, the highest reported levels in the Great Lakes and possibly any surface water ecosystem.* These high numbers can be attributed to high nearshore population densities, a feature unique to inland waterways that does not similarly influence remote ocean basins, and the long hydraulic residence time of some of the Great Lakes (3–100s of years, depending on the lake). Given this time and the recalcitrance of plastic to degradation, *fragments of some of the first plastic ever produced for the consumer market are certainly present in the Great Lakes still today.* This scenario is likely representative of lakes worldwide, which account for 87 percent of the planet's surface freshwater and have an average residence time of 50–100 years[f]—indeed spanning the introduction of plastics to the consumer market.

We know plastic is there in our critical freshwater. What is next? "Although we are all responsible for microplastics in the environment, getting the entire world to rethink the way it uses synthetic polymers would be a long, arduous process requiring compelling evidence of severe environmental risks (D. Sedlak,[33] included with this report)." Critical to this process and the advancement of this research field are (1) the development of analytical techniques for high-throughput, accurate detection and quantification of micro- and nano-plastic, (2) development of hydrodynamic models to guide (3) targeted research surveys and experiments, to develop (4) a global plastic mass balance transport model ("*Where does it comes from? Where does it go?*"), (5) determination of food web impacts, and ultimately (6) the risk to humans.

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[e] *https://www.glerl.noaa.gov/res/projects/food_web/food_web.html*
[f] *http://journal.frontiersin.org/article/10.3389/fenvs.2017.00045/full#Note4*

These research outputs will define further the ecosystem and public health risks plastic pollution pose to our vital freshwater systems and inform the needed policy, mitigation, and prevention initiatives of the future.

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ADDENDUM 1: Recent editorial on "lessons learned from plastic reearch" by David Sedlak, Editor-in-Chief of Environmental Science and Technology, the premier environmental science journal with focus on emerging contaminants of concern. Sedlak, D. Three Lessons for the Microplastics Voyage. *Environ Sci Technol* **51,** 7747–7748 (2017).

ADDENDUM 2: Publication from University of Michigan that culminated from the bulk of the results discussed in above report. Cable, R., Beletsky, D., Beletsky, R., Locke, B. W., *et al.* Distribution and modeled transport of plastic pollution in the Great Lakes, the worlds largest freshwater resource. *Frontiers in Environmental Science* **5,** 40 (2017).

ADDENDUM 1

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THREE LESSONS FOR THE MICROPLASTICS VOYAGE

Whether it is DDT, perchlorate, perfluoroalkyl substances, or pharmaceuticals, the process through which a contaminant emerges follows a predictable pattern. First, researchers stumble upon a previously unknown contaminant or observe effects on the health of humans or wildlife that they cannot readily explain. Driven by curiosity and a desire to protect the environment, the researchers, operating on a shoestring budget, publish a paper documenting their initial findings. The attention that their research receives results in a wave of papers on detection, occurrence and toxicology of a now-emerging contaminant.

About a decade after the first wave of papers appears the emerging contaminant reaches a crossroads. If the research does not seem to justify action, the funding tide ebbs and the community moves onto other issues. But if there is sufficient ground for concern, a second wave of research starts, with an expansion into policy-relevant questions related to establishing regulatory standards, implementing treatment technologies, and reformulating products to minimize future releases.

Microplastics are our newest emerging contaminant. Although scientists have expressed concerns about the *impacts of plastic pollution* for over four decades, *microplastics did not become emerging contaminants* until 2007. The issue gained momentum about five years later, when researchers reported the presence of *microbeads from consumer products* in wastewater effluent-receiving waters. Facing negative publicity for a nonessential ingredient, leading manufacturers voluntarily eliminated microbeads and accepted the *decision to ban them* in the United States in 2015. Now that we are into the second wave of research that will determine whether or not the remaining sources of microplastics will be controlled, it is worth considering lessons learned from other emerging contaminants.

The first lesson is that occurrence data and laboratory toxicology studies alone are not enough to bring about action when the effects being studied do not involve humans. When it comes to wildlife, adverse effects must be documented in the field. In the case of DDT, the direct link between tissue levels and reproductive failure of bald eagles and brown pelicans turned the tide on a product that was considered essential to farmers. In contrast, the widespread occurrence of polybrominated diphenyl ethers (PBDEs) and perfluoroalkyl substances in polar bears garnered plenty of media attention, but without field evidence of adverse effects, regulatory actions were hard to justify. For microplastics, the public might not be as motivated if the adverse effects are limited to decreased feeding by microscopic creatures living near the bottom of the food web. Furthermore, waterways with the highest concentrations of microplastics are also subject to other pollutant stresses that could make it difficult to attribute compromised wildlife health to microplastics. To prove adverse effects of microplastics under realistic conditions, dosing of entire lakes, using methods similar than those used to document *the effects of ethinyl estradiol on fish populations,* might be needed. Because the addition of microplastics to pristine ocean waters would be impractical, such large-scale manipulations would require researchers to devise clever ways of removing microplastics from already contaminated marine waters.

Turning our attention to people, the second lesson is that contaminants are more likely to emerge if there is a reasonable possibility that their use is endangering human health. For example, when PBDEs were reported in human serum and breast milk, regulators took action before health effects were documented. As long as we consider human health as our top environmental priority, occurrence data and toxicology studies suggesting that contaminant concentrations are approaching a level of concern can bring about action. In the case of microplastics, human health risks have been posited, but the complexities associated with microplastic uptake as well as the simultaneous exposure of people to a myriad of other particles are going to challenge researchers seeking to assess the health risks of microplastics. Furthermore, one of the *human health concerns* that is frequently discussed—namely that microplastics expose people to lipophilic chemicals—is likely to be seen as an issue that is best handled by controlling the lipophilic chemicals rather than the media that increase their uptake.

The third lesson is that the likelihood that society will control an emerging contaminant is inversely proportional to the cost of solving the problem as well as the degree to which blame can be affixed on a small number of companies. The first part of this lesson is intuitive: expensive regulatory action requires a high threshold of evidence. Replacing microbeads in facial scrubs is a lot easier than rethinking the thousands of uses of plastics in the economy. The second part is less obvious but just as relevant: product bans and requirements to clean up contamination are more likely when only a few companies manufacture and use the chemical. For example, Monsanto, Westinghouse, and General Electric spent over $10 billion cleaning up PCB-contaminated sites. In contrast, the hundreds of companies that mine and use copper in construction materials, electronics and brake pads have not funded upgrades to sewage treatment plants or the installation of stormwater treatment systems in places where waterways are contaminated with the metal.

If it turns out that a specific use of plastic accounts for a disproportionate share of the microplastics detected in the environment, action is more likely. As long as researchers focus on a suite of sources that would be nearly impossible to eliminate, control options implemented in the near term are likely to be restricted to relatively inexpensive practices (e.g., litter control campaigns, marketing of biodegradable plastics to eco-friendly consumers) that might ultimately have little impact. Although we are all responsible for microplastics in the environment, getting the entire world to rethink the way it uses synthetic polymers would be a long, arduous process requiring compelling evidence of severe environmental risks.

The science and engineering of microplastics will be different from that of the chemical contaminants that preceded them. Nevertheless, we should learn our emerging contaminant history lessons. As we embark on our second decade of microplastics research, we need to set our sights on how best to provide society with the information needed to decide what to do about our newest emerging contaminant.

DAVID SEDLAK,
Editor-in-Chief.

Notes

Views expressed in this editorial are those of the author and not necessarily the views of the ACS. The author declares no competing financial interest.

ADDENDUM 2

frontiers in Environmental Science

ORIGINAL RESEARCH
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Distribution and Modeled Transport of Plastic Pollution in the Great Lakes, the World's Largest Freshwater Resource

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Most plastic pollution originates on land. As such, freshwater bodies serve as conduits for the transport of plastic litter to the ocean. Understanding the concentrations and fluxes of plastic litter in freshwater ecosystems is critical to our understanding of the global plastic litter budget and underpins the success of future management strategies. We conducted a replicated field survey of surface plastic concentrations in four lakes in the North American Great Lakes system, the largest contiguous freshwater system on the planet. We then modeled plastic transport to resolve spatial and temporal variability of plastic distribution in one of the Great Lakes, Lake Erie. Triplicate surface samples were collected at 38 stations in mid-summer of 2014. Plastic particles >106 μm in size were quantified. Concentrations were highest near populated urban areas and their water infrastructure. In the highest concentration trawl, nearly 2 million fragments km^{-2} were found in the Detroit River—dwarfing previous reports of Great Lakes plastic abundances by over 4-fold. Yet, the accuracy of single trawl counts was challenged: within-station plastic abundances varied 0- to 3-fold between replicate trawls. In the smallest size class (106–1,000 μm), false positive rates of 12–24% were determined analytically for plastic vs. non-plastic, while false negative rates averaged ~18%. Though predicted to form in summer by the existing Lake Erie circulation model, our transport model did not predict a permanent surface "Lake Erie Garbage Patch" in its central basin—a trend supported by field survey data. Rather, general eastward transport with recirculation in the major basins was predicted. Further, modeled plastic residence times were drastically influenced by plastic buoyancy. Neutrally buoyant plastics—those with the same density as the ambient water—were flushed several times slower than plastics floating at the water's surface and exceeded the hydraulic residence time of the lake. It is likely that the ecosystem impacts of plastic litter persist in the Great Lakes longer than assumed based on lake flushing rates. This study furthers our understanding of plastic pollution in the Great Lakes, a model freshwater system to study the movement of plastic from anthropogenic sources to environmental sinks.

Keywords: plastic debris, Great Lakes, freshwater pollution, transport model

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INTRODUCTION

In recent years, anthropogenic litter in the form of plastic debris has been documented in widespread and diverse marine (Law et al., 2010, 2014; Cózar et al., 2014; Fischer et al., 2015; van Sebille et al., 2015; Law, 2016), freshwater (Eriksen et al., 2013; Free et al., 2014; Mani et al., 2015; Baldwin et al., 2016; Mason et al., 2016), and even aeolian (Dris et al., 2015) biomes. It is estimated that 4.8–12.7 million tons of plastic enters the ocean in a single year (Jambeck et al., 2015), with a quarter of a million tons currently floating in the world's oceans (Eriksen et al., 2014). It is estimated that 70–80% of marine litter (most of which is plastic) originates from inland sources via rivers (GESAMP, 2010). In the absence of mechanisms to incentivize improved waste management and behavior change, this number will continue to rise, reflecting the exponentially increasing global production of plastic goods (PlasticsEurope: Association of Plastics Manufacturers, 2015). Studies have shown that aquatic organisms ingest plastic pollutants (Boerger et al., 2010; Foekema et al., 2013). Consumption results in energetic and fitness costs (Besseling et al., 2012; Wright et al., 2013) and other morbid impacts (Rochman et al., 2013). There is a high likelihood that humans are consuming plastic derived from fish and shellfish (Van Cauwenberghe and Janssen, 2014; Rochman et al., 2015b), with as of yet unknown health consequences. In the wake of these discoveries, the United Nations has declared plastic pollution among the most critical emerging environmental issues of our time (UNEP, 2016). The scientific consensus is that plastic pollution must be reduced to avoid the risk of irreversible ecosystem harm (Rochman et al., 2016). Yet, an incomplete understanding of the global plastic litter budget hinders the strategic development of mitigation and prevention policy. To effectively target major sources and pathways, the question remains: what drives the concentration and flux of plastic debris across environmental reservoirs?

Plastic pollution first was reported in the ocean over 40 years ago (Carpenter and Smith, 1972; Colton et al., 1974; Wong et al., 1974) and has continued to be a focus of extensive research efforts (Moore et al., 2001; Thompson et al., 2004; Law et al., 2010, 2014; Cózar et al., 2014). Recently, there has been a call to bring similar focus to freshwater (Wagner et al., 2014; Dris et al., 2015; Eerkes-Medrano et al., 2015). Concentrations of microplastics—plastics <5 mm in the largest dimension—in lakes and rivers have been reported as high, or higher, than in central oceans gyres (Eriksen et al., 2013; Castañeda et al., 2014; Free et al., 2014; Lechner et al., 2014; Yonkos et al., 2014; Corcoran et al., 2015; Mani et al., 2015; Baldwin et al., 2016; Mason et al., 2016). Freshwater ecosystems play a critical role in the global water cycle and human health. They connect the inland watersheds that provide drinking water for most of the global population. It is essential to understand the nature and impacts of emergent contaminants, such as, plastic litter, their associated persistent organic toxins (Koelmans et al., 2016; O'Connor et al., 2016), and properties of plastic-toxin interactions (Hankett et al., 2016) to effectively preserve this resource.

The North American Great Lakes system contains one-fifth of the world's freshwater and is arguably one of the continent's most valuable natural resources. Field surveys have confirmed the presence of microplastics in Great Lakes surface water (Eriksen et al., 2013; Mason et al., 2016), sediment (Corcoran et al., 2015; Ballent et al., 2016), and beaches (Zbyszewski and Corcoran, 2011; Hoellein et al., 2014; Zbyszewski et al., 2014; Driedger et al., 2015), as well as the rivers (Baldwin et al., 2016) and wastewater treatment plant (WWTP) effluents (Michielssen et al., 2016) that directly feed into the Great Lakes. Yet, these data are sparse. There is currently insufficient knowledge of spatial and temporal resolution of plastic debris in the Great Lakes to efficiently focus strategic mitigation and management.

The study of plastic in the environment is a rapidly growing field of research. Studies from many sectors have employed diverse analytical methods for the isolation, identification, and quantification of plastic particles in environmental samples. While studies continue to resolve the limits of the myriad new methods used, it remains difficult to obtain, with meaningful throughput and accuracy, a seemingly simple data type: plastic counts. For instance, in the absence of replicate sampling, we do not know how representative single samples are of the environments from which they are collected. Further, most studies rely on visual inspection of samples to identify and count plastic particles. Yet, visual identification can incur error rates from 20 (Eriksen et al., 2013) to 70% (Hidalgo Ruz et al., 2012), with nearly 99% misidentification for sediment samples (Löder and Gerdts, 2015). These challenges hinder future research efforts, as well as our ability to leverage existing data describing environmental plastic.

In this study, we addressed five objectives and sought to answer: (i) What is the spatial distribution of plastic litter across three of the Great Lakes (Lakes Superior, Huron, and Erie) and one connecting lake (Lake St. Clair) down to the smallest particle size yet explored (106 μm)? We hypothesized that plastic concentrations would correlate with proximity to urban areas and that the concentrations observed would dwarf those reported using a larger size cut-off (333 μm; Eriksen et al., 2013). (ii) How is the distribution and the residence time of plastic litter influenced by physical properties of the plastic particles (e.g., buoyancy)? We hypothesized that neutrally buoyant particles, which move three dimensionally through the water column, would have a longer residence time than floating particles that experience surface drift only. (iii) Do permanent features of high plastic pollution exist (e.g., a "Lake Erie Garbage Patch") where mitigation could be focused? Based on existing hydrodynamic models of Lake Erie that predict summer convergence (Beletsky et al., 2013), we hypothesized that permanent features of high plastic pollution would exist in surface drift models and field survey data in anticyclonic anomalies. To inform method development and data interpretation in this study and across the field, we sought to answer (iv) how variable are plastic concentrations among triplicate trawls sampled consecutively at the same location? We hypothesized that within-station variability in count data would not be even across sites, but rather could depend on weather and sampling conditions. Finally, we asked (v) what is the false-positive rate for discerning plastic from non-plastic particles based on visual inspection? As dozens of previous studies have relied on visual inspection alone, we hypothesized that false-positive rates would be <50%, implying that this method was not prohibitively error-prone. Collectively, these efforts lead to a better understanding of the drivers of freshwater plastic pollution in the Great Lakes and around the globe.

MATERIALS AND METHODS

Lake Sampling

To assess the spatial distribution of plastics across three Great Lakes and Lake St. Clair (objective i) surface water samples were collected at 38 stations (**Figure 1**) throughout the summer (May–August) of 2014 using a rectangular manta trawl 16 cm high by 61 cm wide towing a 100 μm Nitex mesh net 3 m long (Wildco) with a 100 μm Nitex mesh cod-end 28 cm long by 15.5 cm in diameter and a flowmeter (General Oceanics Model 2030R Mechanical Standard Rotor). The net was towed outside the wake of the boat at ~2 knots for 20 min. For precision comparison at each station (objective iv), consecutive triplicate trawls were performed over the same transect. The difference in flow meter readings was multiplied by the manufacturer rotor constant and the width of the net mouth to calculate the area of water sampled. In order to standardize and compare plastics concentrations with previous studies (Eriksen et al., 2013; Mason et al., 2016), counts were divided by respective trawl area to achieve concentrations of plastics km^{-2}.

Stations were categorized as basin (>12 km from coast, $n = 7$), non-urban (<12 km from coast with <5,000 inhabitants km^{-2}, $n = 15$), urban (<12 km from coast with >5,000 inhabitants km^{-2}, $n = 6$), river plume ($n = 5$), and WWTP (sampled from environment near where final effluent is released, $n = 5$; **Figure 1**). Environmental data describing conditions at the start of each trawl, including wind speed, cloud cover, water temperature, air temperature, wave height, eastward surface water velocity, northward surface water velocity, wave direction, and wave period, were collected from the Great Lakes Observing System Point Query Tool of the Great Lakes Coastal Forecasting System[1]. Hourly data (or 3-h data, in the case of water temperature) for before and after the start time of each trawl were pulled, and the average was weighted by the number of minutes between data points. Descriptors of all trawls are available (Supplementary Data Sheet 1) where data interpolation was possible (e.g., no data existed for stations in Lake St. Clair or rivers).

Samples were recovered by rinsing the contents of the cod-end into a series of brass-framed sieves (Humboldt Mfg. Co.; Elgin, IL, USA) with stainless steel mesh sizes 4.75 mm, 212 μm, and 45 μm (**Figure 2A**; Humboldt Mfg. Co.). Each fraction was rinsed into a plastic bottle (HDPE bottle, PP screw top, Fisher Scientific 03-313-6C, 03-313-6B) with 70% ethanol for

[1] http://data.glos.us/glcfs/

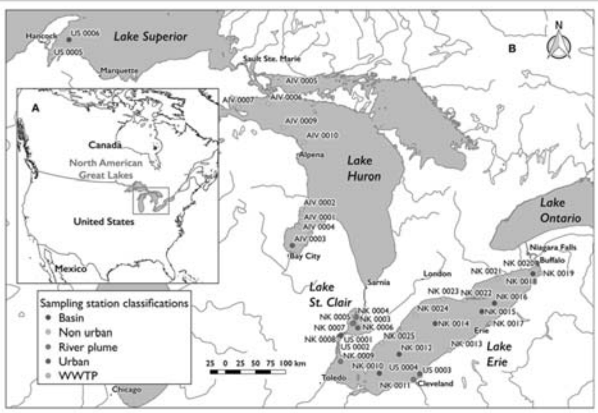

FIGURE 1 | Maps of all stations sampled. Each station contained replicate trawls. **(A)** Overview and location of the North American Great Lakes on the North American continent. **(B)** Station locations and classifications in Lake Superior, Lake Huron, Lake St. Clair, and Lake Erie.

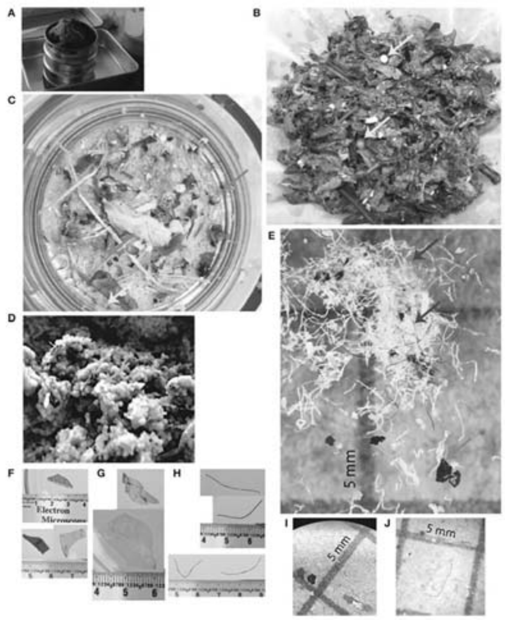

FIGURE 2 | Photographs of samples at various stages of processing, as well as examples of different shape classes. Arrows indicate plastic amidst co-sampled nonplastic organic matter; blue: fragment, dark red: line, yellow: nurdles, cyan: sphere/bead, brown: fiber. **(A)** Bulk sample directly upon retrieval from Manta on a stack of a series of sieves. This sample contained an abundance of algal biomass. **(B)** Bulk sample drying on a 53 μm mesh net. **(C)** Sample after enzymatic processing, which included an incubation in hydrogen peroxide that bleached much of the non-plastic organic matter. This bleaching aided in differentiating plastic (tended to retain color) from non-plastic (prone to bleaching) particles. **(D)** Examples of plastic of sphere class; zoomed in subset of sample in **(B)**. **(E)** Smallest size fraction (106–1,000 μm) after WPO. Note colored plastic fibers (brown arrows) enmeshed in mass of natural fibers bleached white from hydrogen peroxide treatment. **(F–H)** Examples of plastic of fragment, film and line shape classes, respectively; ruler markings are in cm units. **(J,I)** Examples of plastic of paint chip and fiber shape classes, respectively; grid squares are in 5 mm units.

preservation. Sampled items that were too large to fit in a bottle were stored in Ziploc XL bags for later examination. All liquids used directly on the samples were filtered through 100 or 20 μm Nitex mesh in the field.

Sample Processing and Counting

Field-collected samples were spread over 53 μm Nitex mesh (**Figure 2B**), weighed for wet mass, dried at 60°C, and subsequently weighed for dry mass. Large pieces of organic material (e.g., sticks, leaves, etc.) were removed manually. The sample was mixed at a 1:1 ratio with 10% sodium dodecyl sulfate (Acros Organics 226140025) and incubated at 50°C, rotating at 80 rpm for least 24 h. Samples were then size-fractionated through a series of brass and stainless steel sieves (Humboldt Mfg. Co.; Elgin, IL, USA) with mesh sizes 4.75 mm, 1,000 μm, and 106 μm.

The 106–1,000 μm fraction of each sample was digested to remove non-plastic labile organic matter. The first digestion method used consecutive incubations with proteinase, cellulase, and chitinase, followed by incubation in 30% H_2O_2 for 24 h [*sensu* (Lorenz, 2014); **Figure 2C**: sample images]. Following the release of a NOAA Marine Debris Technical Memorandum providing guidelines on the analysis of microplastics in the marine environment (Masura et al., 2015), all previously processed samples were re-processed, and all subsequent samples were processed using only the wet peroxide oxidation (WPO) protocol recommended therein (2015). After oxidation, the remaining material was filtered over 104 μm stainless steel filters (TWP Inc., 150 Mesh T304 Stainless 0.0026; Berkeley, CA), and transferred to a glass petri-dish with 70% ethanol and dried.

Plastic pieces were manually pulled from the <4.75 mm fraction. The raw 1.00–4.75 mm and digested 106–1,000 μm fractions were visually sorted with the aid of a stereo dissecting microscope (10–80x; Zeiss SteREO Discovery.V8; Oberkochen, Germany). Each plastic piece in the two larger size classes was categorized by shape (**Figures 2E–I**): fragment (secondary plastic broken down from larger debris), film (e.g., thin plastic from bags and wrappers), fiber (e.g., individual filaments of textile threads, very thin and frequently curled), line (e.g., fishing line, straighter, and thicker than fiber), nurdle (preproduction plastic pellet), sphere, foam, or paint (consistent with multiple studies that consider paint a plastic or confirm it is composed of, e.g., alkyds and (poly)acrylate/styrene; Lima et al., 2014; Kang et al., 2015; Neves et al., 2015; Song et al., 2015; Imhof et al., 2016; Nizzetto et al., 2016). Such detailed categorization was not possible for the smallest size class (106–1,000 μm), so the smallest particles were classified as either fragment or fiber.

Substantial effort was invested in gaining experience and establishing confidence in visually and tactilely distinguishing plastic from non-plastic particles, especially in the smallest (106–1,000 μm) size class. A collection of characteristics was established to distinguish plastic from non-plastic and to categorize plastics into morphological types. Physical features (color, hardness, fragility, shape) were considered. Features that frequently indicated plastic fragments included: malleability (not brittle), defined jagged shape, shiny surface, and presence of artificial dyes. Dye-free plastic particles were identified by their opaque and white nature. Features that often indicated an inorganic particle included: brittleness or unresponsiveness to force applied by tweezers, audible scratching noise when scraped, transparency, and well-defined crystalline structures and right-angle fractures.

Precaution was taken to minimize risk of sample contamination from handling and the laboratory environment. All liquid that came in contact with the samples (water for sieving, ethanol for storing) was filtered to remove particles >10 μm, glassware for storage was blasted with high-pressure air before use. Thin Teflon sheets (0.005 "Natural Virgin PTFE Roll Stock 12" Wide, Ridout Plastics Co. Inc.) were inserted between storage glassware and their plastic screw tops, as Teflon is rare among environmental plastics and its diagnostic fluoride ion could be detected analytically downstream if contamination did occur. Samples were processed in a laminar-flow or fume hood and remained covered otherwise. Cotton laboratory coats were worn by all individuals. Blank samples consisting of one 1,500 ml and two 500 ml aliquots of 10 μm-filtered MilliQ were processed and counted alongside field samples to account for environmental plastics incorporated during the sampling process that would lead to false positive plastic counts.

All data treatment and statistics were performed using the R statistical environment (version R-3.3.1; Team, 2014). All R code generated to create figures and perform calculations is freely available[2,3] Maps of trawl locations and counts were generated with Quantum GIS (v. 2.18; QGIS Development Team, 2016).

Scanning Electron Microscopy Energy-Dispersive X-Ray Spectroscopy (SEM-EDS)

To assess human error and determine our false positive vs. false negative rates in the assignment of the smallest particles as plastic (objective v), a subset of particles from the smallest size class were randomly chosen from each of the suspected plastic ($n = 10$) and suspected non-plastic particle ($n = 10$) pools across 10 trawls. These particles were characterized analytically (described below). In addition, we prepared a library of 35 known standards to inform our ability to differentiate plastic, mineral, and non-synthetic organic matter and identify potential contamination of our samples from plastic in the processing environment. Standard items included virgin polymers, plasticware, and instruments used for sample collection, processing, and storage, paint from a sampling vessel (R/V *Nancy K*), fibers from lab coats, hair from sample processors, phytoplankton carcasses, and mineral particles.

SEM-EDS was performed to acquire an atomic signature for the 260 particles and standards assessed. Particles were mounted on an SEM peg (0.5 in. diameter; Electron Microscopy Sciences, Cat. 75160; PA, USA) with a piece of double-sided carbon tape (Electron Microscopy Sciences, Cat. 77816; PA, USA). A thin layer (~40 nm) of gold was applied to the sample using a gold sputter coating machine (120 s, Denton Vacuum Inc., Desk II, Cherry Hill, N.J.). Each particle was imaged using a JEOL JSM-7800F SEM at an accelerating voltage of 15 keV and an acquisition time of 20 s. A rectangular well-focused central area on each particle was excited via EDS. The resulting spectra were analyzed with Oxford AZtec 3.1 EDS software. The auto-ID function using default parameters verified the presence of elements on the surface of each particle. Following data acquisition, particles were assigned to each of three classes based on peak elements and surface texture: inorganic/mineral (IO), non-plastic (NP) organic matter, and plastic (P). Some gradation was allowed between discrete classes resulting in 5 different categories: P, P-NP, NP, NP-IO, IO.

Lake Erie Plastic Transport Model

It is not feasible to perform the high-resolution spatial and temporal sampling required to understand the lake-wide distribution and movements of plastic pieces. Thus, a Lagrangian particle transport model previously used in Lake Erie (Michalak

[2]https://github.com/DuhaimeLab/Frontiers_2017_GreatLakesPlasticDistrib
[3]http://www-personal.umich.edu/~duhaimem/Rpubs_code/GreatLakes_Plastic_Pollution_Study_Cable_etal_2017.html

et al., 2013; Fraker et al., 2015; Beletsky et al., 2017) was applied to simulate transport of microplastics over a variety of timescales and plastic properties (e.g., its buoyancy; objectives ii and iii). In this model, particle trajectories were calculated with the hydrodynamic model velocity recorded at regular time intervals (e.g., hourly). For each particle, the gridded velocities were interpolated to its location and the particle was moved to a new location based on the interpolated velocity and the time step of the particle transport model (Lynch et al., 2014). The three-dimensional particle trajectory code is based on the second order accurate horizontal trajectory code, as described in Bennett and Clites (1987), with the addition of vertical position tracking. Plastic "particles" in the model are neutrally buoyant (i.e., have the same density as the ambient water), passive (i.e., they follow local three-dimensional currents), and biochemically inert. If collision with model boundaries occurs, particles remain in the nearshore zone. The model includes horizontal and vertical diffusion, as introduced by Smagorinsky (i.e., with a non-dimensional coefficient of 0.005 in the horizontal diffusion parameterization; Smagorinsky, 1963) and random-walk approaches, respectively. Vertical diffusion was set at 5×10^{-4} m^2 s^{-1}. Because the size of most particles in this study is <1 mm, they are considered fully submerged and therefore windage is zero. In experiments that examine the effect of plastic buoyancy on residence time and transport, floating particles were driven by surface currents only, which were obtained from the top layer of the 3D hydrodynamic model.

Advection fields used by the particle model were produced by the three-dimensional finite-difference hydrodynamic model based on the Princeton Ocean Model (Blumberg and Mellor, 1987), driven by the wind, heat flux, and tributary flow from 22 major rivers and two outflows (listed in Schwab et al., 2009). The hydrodynamic model used a uniform 2 km horizontal grid with 21 vertical levels. Six years of hourly current data (2004–2005, 2007, and 2009–2011) obtained from previous applications (Beletsky et al., 2013) were used to model microplastic transport in summer months (including the month of June, the month of Lake Erie field sampling). In addition, year-long simulations were conducted when particles were continuously released throughout each year. To calculate residence times, the sequence of years was looped because longer time periods were required to flush the vast majority of particles from the lake.

In each model simulation, virtual particles were released daily to Lake Erie surface water at 29 tributaries (Supplementary Table 2) and two WWTPs in the Cleveland area. Particles left the lake through Niagara River and Welland Canal (easternmost edge of Lake Erie). For residence time calculations, particles were released during the first year (2004) and then tracked until the percentage of particles remaining in the lake dropped to 1% (eight years for neutrally buoyant particles).

RESULTS AND DISCUSSION

This dataset represents the largest single-season effort of plastic quantification in the Great Lakes to date. Plastic was counted in 108 surface trawl samples, which spanned 38 stations across Lakes Superior, Huron, St. Clair, and Erie. Plastic was found at every station sampled (**Figure 3**). The trawl with the highest total concentration of plastic contained 4-fold higher plastic than yet reported in the surface of the Great Lakes (Eriksen et al., 2013; Mason et al., 2016). The vast majority of plastic counted was <1 mm in size (**Figure 4A**).

Concentrations and Distributions of Great Lakes Plastic

Plastic Concentrations Were Highest at Urban Centers

Total plastic abundances per surface trawl spanned an order of magnitude. They ranged from 1,910,562 particles km^{-2} in the Detroit River plume (NK0008-3) to 126,933 particles km^{-2} in the Straits of Mackinac in Lake Huron (NK 0007-1; **Figure 3D**; Supplementary Data Sheet 1). Notably, these total concentrations and all that follow do not include counts of fibers, as during sample processing it became evident that fibers could not be quantified with equally high confidence across size fractions, an issue which is discussed at length below. Fiber concentrations were analyzed separately to explore patterns in the data.

The highest concentrations of plastic were found in samples collected within 12 km of the coast of populated urban cities, in river plumes, or directly at the effluent of WWTPs (**Figures 3, 4B**). All of the most concentrated samples but one were collected in Lake Erie or the urban river and estuary-like lake directly feeding it (Detroit River and Lake St Clair; **Figure 2**). Our empirical data support recent model predictions that the loads of Lake Erie plastic inputs are 4- and 80-fold higher than Lakes Huron and Superior, respectively (Hoffman and Hittinger, 2017). Notably, the plastic input loads for this model were scaled to census-derived population density of the coastlines (Hoffman and Hittinger, 2017)—an underlying presumed correlation our field data support. The lowest counts were collected at non-urban coastal stations and offshore basin stations, with the exception of the deepest point of the Eastern Basin of Lake Erie (**Figures 3, 4B**). These findings support previous reports of a correlation between plastic concentrations and proximity to urban centers in the Great Lakes (Baldwin et al., 2016), as well as other enclosed and semi-enclosed aquatic environments across the world, such as, tributaries to the Chesapeake Bay, USA (Yonkos et al., 2014), the Bay of Brest in France (Frère et al., 2017), the Xiangzi Bay upstream of the three Gorges Dam (Zhang et al., 2017), inland lakes around Wuhan, China (Wang et al., 2017), and estuaries in and around Durban, South Africa (Naidoo et al., 2015). Attributes that are likely to contribute to elevated plastic concentrations in urban vs. non-urban locales include higher population densities (Jambeck et al., 2015), increased particulate aeolian inputs (including plastic; Dris et al., 2015), and increased areas of impervious substrate. The percent of a watershed comprised of impervious substrate is positively correlated with higher plastic concentrations in the Great Lakes watershed (Baldwin et al., 2016), likely due to greater volume and higher velocity runoff during storm and snow melt events. The higher concentrations in river plumes

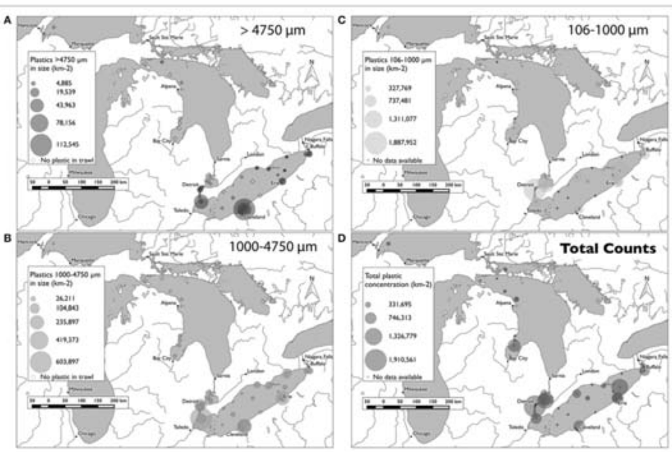

FIGURE 3 | Maps of plastic concentrations across the lakes sampled, where magnitude of concentration is depicted by size of circle around trawl location. Note, fiber counts are not included in these figures, as discussed below. **(A)** Mapped counts of plastic litter >4,750 μm. **(B)** Mapped counts of plastic litter 1,000–4,750 μm. **(C)** Mapped counts of plastic litter 106–1,000 μm. **(D)** Total mapped counts for the stations where all three size classes were quantified.

and near WWTP effluents than in coastal areas (**Figure 4B**) suggest these inputs to be sources (McCormick et al., 2014) and that plastic debris enters this system from inland waterways and human activity. Increasing the degree of pervious substrate in watersheds, such as, the implementation of green infrastructure catchments, should be explored as an effective measure to capture plastic debris in runoff and reduce loads ultimately reaching waterways. As the number of storm events is expected to increase with a changing climate (IPCC, 2012), such innovations are timely to preventatively buffer our freshwater systems from being inundated with stormwater-delivered debris.

Single Trawls Are Imprecise: Within-Station Variability Can Vary 3-Fold

This is the first survey of freshwater plastic litter to address variability in counts by conducting replicate trawls at each of 38 stations. The distributions of all trawl concentrations, total concentrations, and station concentrations deviated significantly from normal distribution (Shapiro Wilks test, $p << 0.01$) with high skewness (1.9–6.62) and kurtosis (3.5–49.25; Supplementary Figure 1). As a result, non-parametric tests were used (e.g., Spearman's rank correlation) and metrics that do not represent strongly skewed data (e.g., standard deviation) were not used to describe and interpret the results. Rather, to assess factors that influence within-station variability, we calculated a metric we termed the mean-normalized range (MNR) by dividing the count range (max–min) of each station by the mean of the station.

The vast majority of trawl concentrations from the same station varied more than 100%, as depicted by a mean normalized range (MNR) >1 (**Figure 5**; Supplementary Data Sheet 3). In other words, the accuracy of a single trawl at one station is quite low and repeated trawls at the same location can vary in precision by up to 3-fold. We suspect that the magnitude of MNR at certain stations is due to undersampling. Precision increases as the plastic concentration sampled increases, as MNR is significantly negatively correlated with total trawl concentration (Spearman's $rho = -0.629$, $p = 0.000$; **Figure 5**). MNR is <1 for all counts in the smallest size class, which have the largest concentrations ($M = 0.09$) and most frequently >1 in the largest size class ($M = 1.94$; **Figure 5**, Supplementary Figure 2), which have relatively lower concentrations. While dependent on plastic concentration, the MNR was not significantly influenced by air velocity ($rho = -0.093$, $p = 0.245$), east-west surface current velocity ($rho = -0.072$, $p = 0.364$), wave period ($rho = -0.078$, $p = 0.330$), or wave height ($rho = -0.093$, $p = 0.242$)—all local conditions that could influence the distribution of plastics at the water surface

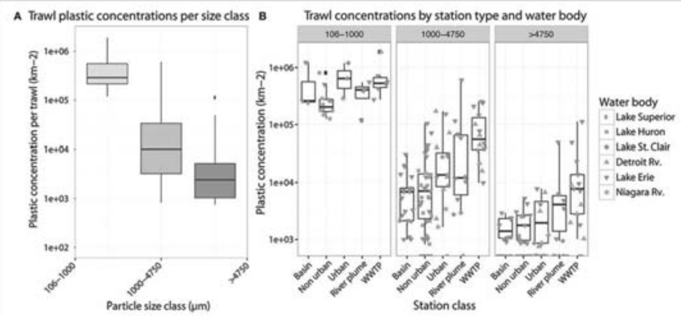

FIGURE 4 | (A) Boxplots depicting the means and spreads of all individual trawl counts by particle size fraction. **(B)** Boxplots depicting the means and spreads of individual trawl counts by size class, station type, and water body: Lake Superior (pink square), Lake Huron (brown square), Lake St. Clair (green diamond), the Detroit Rv. (blue upright triangle), Lake Erie (dark blue upside-down triangle), and the Niagara Rv. (purple star).

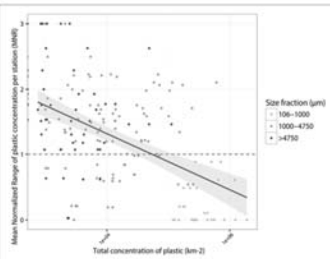

FIGURE 5 | Plot of trawl mean normalized ranges (MNR) across stations vs. the log of plastic concentration in each individual trawl. Regression line of the linear model used to predict MNR from plastic concentration is shown (R^2 = 0.442, slope = −0.357, intercept = 2.737, $p < 2.2e{-}16$). The gray band depicts the 95% confidence level interval for predictions from the linear model.

between trawls. However, longitudinal surface current velocity positively varied with MNR ($rho = 0.166, p = 0.037$); an increase in north-south current velocity was correlated with a decrease in precision between trawls. As currents in the lake are mostly wind-driven and winds on Lake Erie predominantly blow west to east, increases in north-south current velocity may indicate a local weather anomaly, such as, a squall or storm. These features are known to build up and die down quickly; it was not uncommon to experience a short burst in weather change over the course of the 1–2 h spent sampling at a single station. Such dynamic local conditions could increase the variability between trawl counts within a single station and decrease the accuracy of a trawl. To maximize reliability of surface plastic counts, we suggest samples not be taken around wind-related weather anomalies.

A similar survey of marine plastic debris assessed variability with replicate sample quantification in the North Pacific Gyre (Goldstein et al., 2013). This study found a mean within-station coefficient of variation (CoV; calculated as the station standard deviation divided by the station mean) of 51.4% for net-collected samples. CoV depends on the station standard deviation, which we deemed an inappropriate representation of data as heavily positively skewed as ours (Supplementary Figure 1). Yet, for purposes of comparison, we determined the CoV across the stations in this study and found they ranged from 1.5 to 173% (Supplementary Figure 3). The CoV of the smallest size class was less than that of the North Pacific study, whereas the CoV of larger size classes was greater (Supplementary Data Sheet 3). In the power analysis performed by Goldstein et al. (2013), statistical power increased when number of samples increased. In the case of our data, within-station variability appeared more influenced by the plastic count in each sample than the number of samples counted (as $n = 28$ for the smallest size class, and $n = 108$ for the two larger size classes). In order to reduce the within-station variability of the larger two size classes at stations with low overall plastic concentrations, greater counts are needed per trawl, thus sampling should occur over a larger area. We suggest a minimum MNR of <1 and ideally lower. As field survey data is time consuming and costly, recognition of this count-dependent variability and the importance of replication is critical

TABLE 1 | Mean and standard deviations of plastic type concentrations (km^{-2}) across all trawls and size classes quantified.

Size (μm)	Fragment	Film	Line	Nurdle	Sphere	Foam	Paint	Total Plastic	*n*
106–1,000	465,606 ± 403,378	NA	NA	NA	NA	NA	NA	465,606 ± 403,378	28
1,000–4,750	19,237 ± 42,995	1,607 ± 3,195	1,109 ± 2,040	3,742 ± 19,500	966 ± 3,343	4,443 ± 12,953	1,115 ± 2,475	32,219 ± 73,576	108
>4,750	2,009 ± 8,500	880 ± 2,883	168 ± 460	19 ± 138	0 ± 0	427 ± 1,865	0 ± 0	3,503 ± 12,766	108

for maximizing the value of such datasets, especially as future field survey studies are designed and implemented.

Plastic Less than 1 mm Dominated the Dataset

The mean concentration of plastic in the smallest size class (106–1,000 μm) was 15-fold higher than the middle size class (1,000–4,750 μm) and 130-fold higher than the largest size class (>4,750 μm; **Figure 4A**, **Table 1**). A similar pattern was maintained in all trawls, regardless of water body or types of stations sampled (**Figure 4B**). These findings are consistent with surveys of other lakes, such as, lakes near Wuhan, China where more than 80% of the plastics found were 2 mm and smaller (Wang et al., 2017). However, plastics 1–5 mm in size were most abundant in sections of the Xiangxi River, perhaps due to a shorter residence time and less weathering while in the river (Zhang et al., 2017). Previous surveys of Great Lakes plastic have found a 40- and 6-fold difference between the smallest and largest size classes (Eriksen et al., 2013; Mason et al., 2016). It is likely that the order of magnitude increase in the relative abundance of the smallest size class between previous Great Lakes surveys and the overall maximum abundance in our study can be attributed to our use of a 106 μm size mesh collection net, as opposed to the 333 μm mesh used previously in the Great Lakes and their tributaries (Eriksen et al., 2013; Baldwin et al., 2016; Mason et al., 2016) and in most aquatic plastic debris surveys to date (Hidalgo Ruz et al., 2012; Law, 2016). As a result, our data more comprehensively capture the "micro" plastic range in the Great Lakes, knowledge of which is critical to our assessments of environmental risk. Smaller plastic particles stay at the water surface longer than larger particles of the same composition and shape (Khatmullina and Isachenko, 2016; Kowalski et al., 2016) and are more readily consumed by smaller organisms in aquatic food webs, increasing the chances of biomagnified effects due to predation (Wagner et al., 2014). Further, the larger surface area to volume ratios of these small particles increases their potential as vectors of adsorbing contaminants (Barnes et al., 2009; Teuten et al., 2009). Future studies should continue to probe this small size class, as well as develop innovative high-throughput solutions to capture and quantify particles below 106 μm and into the nanoscale, where risk may be highest due to subcellular effects (Syberg et al., 2015).

Secondary Plastics (Fragments) Were the Most Common Plastic Type

Fragments were the most abundant plastic shape class across the dataset (**Figure 6**). This finding is consistent with other recent studies that used comparable analytical methods, including a survey of 59 stations in Lake Michigan (79% fragments, 14% fibers; Mason et al., 2016), and even a study in remote Lake Hovsgol, Mongolia (40% fragments, 20% fibers and lines; Free et al., 2014). Rivers and urban effluent (e.g., WWTP) are thought to be major contributors of plastic to freshwater water systems. Notably, studies of sources of plastic to the Great Lakes have documented fibers to dominate, not fragments. An analysis of 29 Great Lakes tributaries (Baldwin et al., 2016) found total debris comprised of 71% fibers and 17% fragments. Similarly, anthropogenic litter in the effluent of a high capacity wastewater treatment plant that discharges directly to the Great Lakes was found to be 61% fibers and 33% fragments (Michielssen et al., 2016).

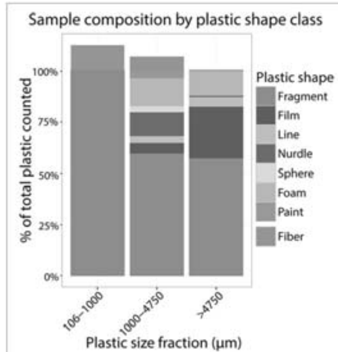

FIGURE 6 | Stacked barplot depicting the relative abundance of different shape classes amongst plastic from each size fraction. The bar to 100% for each size class represent the relative abundance of different shape classes when fibers were not included in the total counts and the portion above 100% represents the relative abundance of fibers in the total counts.

This difference may be due to the fact that typically fibers are comprised of polymers that are denser than water, e.g., nylon, polyester, acrylic. As such, in a stable water body (e.g., large lakes, ocean gyres) they are expected to sink, while in the flow of turbulent mixing systems (e.g., streams, rivers, WWTP effluent, tidal inlets) these fibers may remain mixed and in the seston (Baldwin et al., 2016). Fragments are primarily secondary plastic debris and are likely to be composed of more positively buoyant polymers (e.g., polyethylene and polypropylene, as demonstrated in a study in Lake Michigan; Mason et al., 2016) that float at the lake surface. Alternatively, fibers may be drastically underestimated in surface aquatic environments owing to difficulties collecting fiber data, as discussed below.

When station type was considered, the relative abundances of fragments, foam, and (for the largest size class) film were high in urban and river plume samples—the latter of which were all coincidentally urban, as well (Supplementary Figure 2). Similarly, this trend was observed in river samples, where "litter-related plastic" (the collective class of fragments, foam, and film) was significantly more highly represented in Great Lakes tributaries of watersheds with urban attributes (Baldwin et al., 2016). This may be attributed to proximity to land-based plastic sources, such as, recreation on populated beaches and litter in urban areas and suggests that curbing mismanaged waste in urban centers could reduce the load of plastic in waterways.

Assessing Confidence in Plastic Count Data

Though recommendations (Ryan et al., 2009) and protocols (Masura et al., 2015) have been put forth for sample collection, processing, and quantification, standardized sampling methodology, and reporting are critically lacking (Hidalgo Ruz et al., 2012; Law, 2016). The reasons for these inconsistencies are multifaceted. This is a relatively young field of research with many newly recruited researchers from broad disciplines, e.g., environmental science, biology, chemistry, engineering, physics, oceanography, ecology, bringing diverse backgrounds to a common problem. Each study contributes new insights, but also highlights the Achilles' heel of their given approach. This process is necessary to arrive ultimately at a unified approach. In the present study, the greatest uncertainty arose in the treatment of fiber count data, as well as our ability to visually and chemically discern plastic particles from non-plastic in the smallest size class.

Confidence in fiber count data depends on size class and sorting effort

Fibers were identified in all size classes, yet the degree of certainty in the fiber count data depended on the size class, oxidative treatment of sample, and effort of the sample sorter. First, it is likely that fiber counts from field samples were underestimated because the sampled material was so heterogeneous causing fibers to be missed and unaccounted for. This was especially likely in the larger two size classes (1,000–4,750 μm and >4,750 μm), where WPO treatment was impractical at the volumes needed to be effective and thus could not be used to eliminate bulk non-plastic organic matter. In these fractions, the fibers, which are much less rigid than other plastic morphologies and more prone to "stick" to other objects when wet, were deeply enmeshed in the crevices of or entwined in natural fibers of non-plastic items (e.g., leaves, sticks, bark, feather, etc.) during sieving and sorting. As a result, fibers were difficult to separate from the non-plastic organic matter co-sampled from the lake surfaces, much of which was naturally fibrous (**Figures 2B–E**). This increased difficulty in acquiring fiber counts also required greater effort and vigilance by the person visually sorting, given the enmeshed fibers would be much thinner than other items the sorter was looking for. These issues were much less apparent in the smallest size class, where most non-plastic organic matter was removed chemically and fibers were more obvious with little surrounding or overlapping material. Thus, it is difficult to compare fiber abundance across size classes, as the "sorting effort" required varied widely. Second, owing to their small width and surface area, we could not use the same sensory data that we relied upon to discern plastic fragments from non-plastic particles under the microscope (e.g., squeezing, pinching, scratching, etc.). The small size of fibers also prohibited the controlled physical manipulation needed to perform chemical analysis via SEM-EDS—though we cannot predict whether this led to an over- or underestimate of fiber counts. Notably, these issues did not influence our ability to detect and report concentrations of plastic line. Lines were more discernible and behaved very differently when manipulated owing to their greater length, thickness, and consequent rigidity (**Figures 2A,H,J**).

Finally, fibers were the plastic type most likely to contaminate a sample during processing in this study. All but one of the 126 particles introduced to the blank controls were fibers (Supplementary Table 3). For instance, the 1,000–4,750 μm fraction of a single blank control contained 33 fibers, whereas the maximum raw number of fibers counted in the same size class was 33 and the average across all trawls was 24 (Supplementary Table 3). Further contributing to the underestimate of fibers in field samples relative to sample counts was that blank samples were pristine and easy to see, whereas fibers in field samples were often complex conglomerations of suspected natural and plastic fibers (**Figure 2E**). Though anecdotal evidence derived from observations during processing suggest that the environmental samples contained more fibers than the blanks, the possibility of contamination of samples by fibers could not be ruled out. Fiber contamination during sample processing has been reported previously (Foekema et al., 2013; Dekiff et al., 2014; McCormick et al., 2014; Woodall et al., 2015). A comparison of numbers of fibers introduced using different protocols suggested fiber contamination was introduced primarily as a result of sample sieving and moving from one holding vessel to another (unpublished data; BW Locke, RN Cable). We recommend taking precautions to reduce the number of times a sample is transferred, sieved, or filtered from the beginning of sample collection, in addition to reducing the amount of time a sample is exposed to open air outside of a fume or laminar hood.

It is paramount that the field overcomes the limitations and uncertainties related to the quantification of plastic fibers. Evidence is mounting that fibers are a dominant form of plastic pollution in many aquatic ecosystems—especially fluvial (McCormick et al., 2014; Zhao et al., 2014; Dris et al., 2015; Baldwin et al., 2016), but also in marine beaches and sediment (Browne et al., 2011; Claessens et al., 2011; Woodall et al., 2014; Fischer et al., 2015; Naidoo et al., 2015; Van Cauwenberghe et al., 2015). The ecological implications of these fibers remain to be shown, but plastic fibers are increasingly found in the stomachs and tissues of aquatic wildlife, many of which are consumed by larger animals, including humans (Neves et al., 2015; Rochman et al., 2015a; Vandermeersch et al., 2015; Li et al., 2016). Direct human health impacts have been reported, as well: when inhaled, microplastic fibers are retained the lung tissues and can become associated with malignant tumors (Pauly et al., 1998). We must develop an accurate assessment of the sources, abundances, and impacts of synthetic fibers in our environment so that informed mitigation practices can be put into place, if deemed necessary.

Visual discrimination of plastics is confirmed by analytical methods

While most studies rely on visual inspection alone (reviewed in Hidalgo Ruz et al., 2012; Law, 2016), such human sensory-based observations can be error-prone. First, misidentification can occur due to the similarities in appearances of plastic and non-plastic particles (Filella, 2015). Second, the reliability of visual identification decreases with decreasing particle size. In the smallest size class, we used SEM-EDS analysis to test and reduce our rate of incorrectly differentiating plastic from non-plastic via visual and tactile inspection alone. EDS spectra and SEM images representative of plastic, inorganic, and non-plastic organic particles were highlighted (**Figure 7**). EDS spectra are summarized in Supplementary Data Sheet 2; EDS spectra and SEM microscopic data files are included in Supplementary Image 1.

To address erroneous counts caused by misidentification while sorting, we built a diverse library of standards (described in Supplementary Data Sheet 2). This library was used to train our classification efforts prior to analyzing sample spectra. Among the qualitative anecdotes resulting from the analysis of this library, we learned that microbeads from personal care products all contained the elements C (primary peak), N, Si, and, all but one, O (Supplementary Data Sheet 2). One personal care product (PCP) bead standard had a large Si peak relative to the other

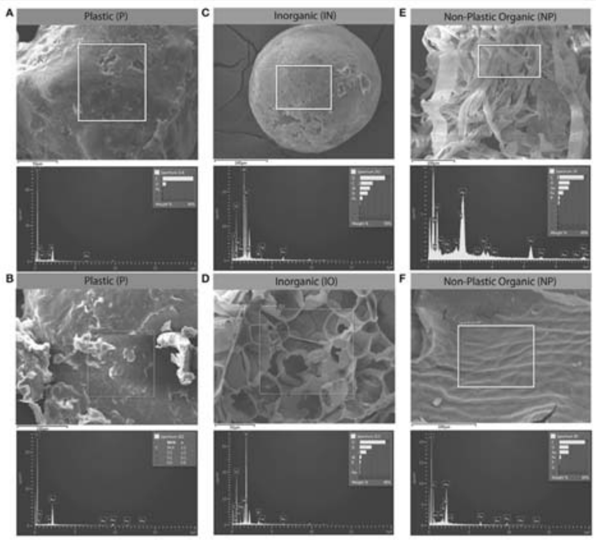

FIGURE 7 | Examples of SEM-EDS spectra and microscopic images representative of the three compositional classes: plastic (P), inorganic (IO), and non-plastic organic (O). **(A)** plastic fragment. **(B)** Flaking, jagged, "crumbly" bead from a personal care product that served as a positive control. **(C)** Coal fly ash from a Lake Erie sample. **(D)** Piece of silica foam from Lake Erie sample. **(E)** Stringy, fibrous organic matter particle from Lake Erie sample. **(F)** Non-plastic organic matter control depicting diagnostic shallow surface veining; likely a leaf or other vegetation.

elements. We attributed this composition to the particle being mica or previously having been in close association with mica. Indeed, sparkling "beads" from PCPs that crumbled upon touch were found often, which we presumed were mica particles, after finding it listed as an inactive ingredient in PCP. Further, all organic matter standards contained Fe (in the presence of O), as did the nylon mesh net that had been used to filter organic material, whereas no Fe was found in pristine virgin polymers. This pattern held until environmental samples were analyzed. As opposed to pristine standards, Fe was detected in nearly all particle types (plastic, non-plastic organic, and mineral) that had been exposed to the environment.

Physical features of the particle surface further informed our classification decisions between plastic and non-plastic organic. Plastic tended to have deep and clean fractures, and smooth surfaces with shallow flakes (e.g., **Figures 7A,B**); though this could be obscured as particles oxidized with age and appeared brittle. Particles with relatively simple elemental spectra consisting of a large primary C peak, frequently with a smaller O peak, were classified as plastic (P; **Figures 7A,B**). Inorganic (IO) particles were best characterized by the presence of a large primary peak of the element Si (**Figures 7C,D**; Supplementary Data Sheet 2). One IO particle (of 47 total) that lacked Si instead contained Ti (Supplementary Data Sheet 2). Many of the IO particles were round spheres suspected to be coal fly ash (**Figure 7C**), a positively buoyant byproduct of coal combustion that has been reported previously in Great Lakes surface waters (Eriksen et al., 2013). Some IO particles physically resembled styrofoam balls but were confirmed to be puffed silica foam, having contained prominent mineral elements (e.g., **Figure 7D**). Non-plastic organic matter (NP) was physically characterized by stringy fibers of irregular width or shallow-relief surface patterns typical of leaf veining (**Figures 7C,F**, respectively) and chemically characterized by more complex elemental signatures with several smaller peaks rather than a single dominant C peak.

To assess our tendency to accurately classify plastic from non-plastic, we compared our initial visual classifications with those based on EDS-SEM analysis (**Figure 8**; Supplementary Data Sheet 2; Supplementary Image 1; Supplementary Table 1). Of all pieces visually identified as plastic, 76% were confirmed as P, 2% were NP, 12% could not be identified as P or NP, and 10% were IO. Of all pieces visually identified as non-plastic, 46% were confirmed as NP, 35% were IO, 11% couldn't be identified as P or NP, and 7% were plastic (**Figure 8**). A chi-squared test of independence confirms that the EDS-SEM-based plastic (P) calls occur most often in the visually-determined plastic category, followed by the P-NP class, and the EDS-SEM-based non-plastic (NP) calls occur most often in the visually-determined non-plastic category, followed by the inorganic (IO), and NP-IO ($\chi^2 = 112.63$, $p = 2.003e\text{-}23$, **Table 2**). These findings provided confidence in the visual discrimination between plastic and non-plastic particles in the smallest size class, and that rates of false-positives in both categories are similar enough that there was no need for adjustments to plastic abundances.

Lake Erie Plastic Transport Model

To develop a more holistic view of plastic transport dynamics than is possible based on discrete field collections and assess

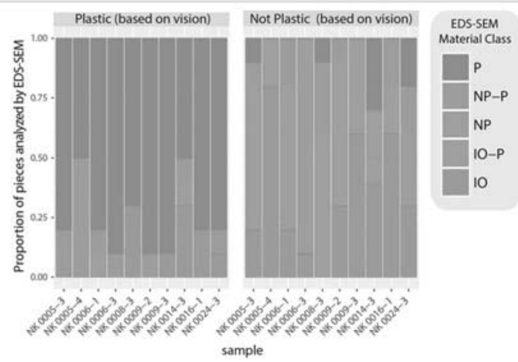

FIGURE 8 | Barplots representing the agreement between visually categorized fragments (plastic vs. non-plastic) and SEM-EDS analytically categorized fragments. SEM-EDS-based classifications fall along a spectrum of three discrete categories: plastic (P), inorganic (IO), and non-plastic organic (NP). This is a visual representation of the contingency table used in the chi-square test of independence (Supplementary Table 1).

the possibility of predicting plastic distributions, we modeled the transport of plastic and tested the effect of plastic buoyancy on the resident times in Lake Erie. Lake Erie is the smallest and shallowest of the Great Lakes, but is disproportionately surrounded by highly populated areas and used heavily for shipping and fishery industries.

No Lake Erie "Garbage Patch," but Prominent Longshore Transport Highlights at-Risk Coastal Areas

For decades, studies have described the presence of an oceanic "garbage patch" (coined in Moore et al., 2001), an amalgam of human-generated trash caught-up in the North Pacific Central Gyre that results from the convergence of floating debris in the anticyclonic eddy of the gyre's high pressure cell (Day and Shaw, 1987; Law et al., 2014). Similar anticyclonic currents form in Lake Erie in summer months (Beletsky et al., 2012) and the high concentrations of plastic in Lake Erie's eastern basin have been attributed to this feature (Eriksen et al., 2013; Driedger et al., 2015). Yet, our plastic transport model did not predict a permanent plastic "garbage patch" in Lake Erie (**Figures 9, 10A**). This lack of a "garbage patch" may be explained by less intense convergence of surface lake currents or by the less persistent lake currents that last on the order of only weeks to months. Comparatively, stable anticyclonic circulation persists in the oceans for much longer time periods.

Results of monthly drift in summer (June, July, and August, each run over 6 years) illustrated the variability of spread due to changing current patterns (**Figure 9**). In early summer, the model generally predicted the eastward drift of neutrally buoyant particles. This was especially pronounced along both the northern and southern coasts in June, the month the majority of our field survey took place. Later in the season, the large-scale anticyclonic circulation that typically develops in mid and late summer (Beletsky et al., 2012) influenced the movement of plastics. Due to that circulation feature,

TABLE 2 | Residuals of chi-squared test of independence performed on the contingency table (Supplementary Table 3) that related the number of samples visually deemed as plastic and not plastic vs. their SEM-EDS-based classification into plastic (P), non-plastic organic (NP), and inorganic (IO) particles.

Visual-based class	SEM-EDS-based class				
	P	P-NP	NP	IO-P	IO
Plastic	5.3554386	0.147442	−4.4907312	−0.7071068	−2.6352314
Not plastic	−5.3554386	−0.147442	4.4907312	0.7071068	2.6352314

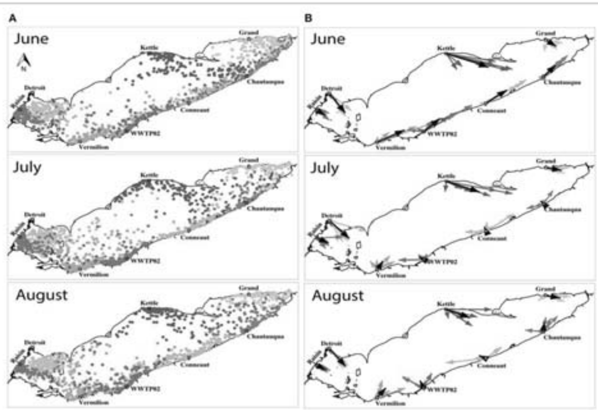

FIGURE 9 | **(A)** The distribution of neutrally buoyant particles at the end of month-long transport in June, July, and August for 6 years. For visual simplicity, 8 of the 29 sources (influents) are depicted: the Raisin Rv. (magenta), Detroit Rv. (cyan), Kettle Rv. (purple), Grand Rv. (turquoise), Chautauqua Rv. (blue), Conneaut Rv. (orange), Cleveland WWTP (red), and Vermilion Rv. (green). **(B)** Mean transport vectors summarizing the positions of all particles at the end of month at each of the same eight representative sources (similarly colored coded). The six vectors per source represent mean transport for each of the 6 years. The 6-year mean vector is shown in black at each input.

FIGURE 10 | (A) Mean residence time (months) for each source of neutrally buoyant particles. Particles were released daily for 1 year and tracked for 8 years (time for 99% of particles to leave the lake). Red dots represent the particles that remain in the lake after 8 years of drift. (B) Percent of particles remaining as a function of time for the neutrally buoyant (right curve) and floating (left curve) models; based on same run conditions as (A).

particles released along the southern coast east of Cleveland were often transported westward (**Figure 9**). During that time, temporary patches (lasting for a few days) formed in the floating particles model. In this case, particle aggregation due to current convergence *is* expected. For example, in mid-August 2010, floating particles aggregated in a large anticyclonic gyre developed in the central basin and two smaller anticyclonic gyres in the eastern basin (Supplementary Figure 4). Overall, particles in both neutrally buoyant and floating cases exhibited general eastward drift and flushed quickly from the western basin by the Detroit River flow (**Figure 10A**). Recirculation in the central and eastern basins was especially pronounced in the summer. Neutrally buoyant particles drifted more slowly than floating particles because of reduction of current speed with depth.

Our model did not predict elevated concentrations of plastic in Lake Erie's eastern basin relative to the central basin, as seen in both our field survey (**Figure 3D**) and that of a prior study in this lake (Eriksen et al., 2013). Notably, this pattern was absent in a recent Great Lakes particle model, as well (Hoffman and Hittinger, 2017). This is despite the fact that the forcing used in the particle model presented here has superior temporal resolution (e.g., hourly vs. three-hourly) and more accurately predicts observed Lake Erie circulation patterns (Beletsky et al., 2013). For example, the winds used in the Hoffman and Hittinger particle model (NOAAs Great Lakes Coastal Forecast System model output) typically produce cyclonic circulation patterns in summer, rather than the anticyclonic patterns observed in summer (Beletsky et al., 2013). We hypothesize that model discrepancy can be either due to a temporary patch in both observational surveys or due to an elevated input near or in the eastern basin that was not accounted for in our model (e.g., Baldwin et al., 2016 documented a peak in microplastic concentration at Ashtabula, OH).

According to the neutrally buoyant particle model predictions, habitats along the southern coast of Lake Erie were predicted to be most affected by plastic pollution (**Figure 9**). The higher concentration of rivers along the southern coast led to more particles released in that area in model runs. The eastward drift of particles from upstream sources (e.g., the Detroit River and other rivers in the western basin) led to higher concentration of particles (**Figure 9**; particle release points identified by open circles and are listed in Supplementary Table 2). This interpretation is consistent with the recognition that rivers are major sources of plastics to inland water bodies (Wagner et al., 2014), including the Great Lakes (Baldwin et al., 2016). In most months, rather than moving offshore, the model predicted longshore transport from coastal sources. This model indicates that future plastic pollution mitigation and management efforts in Lake Erie should focus on its southern shore and downstream of urbanized areas. Extending this plastic transport model to the other four Great Lakes will similarly inform future efforts across this critical watershed.

Plastic Density Drastically Impacts Residence Time in the Lake

The buoyancy of modeled particles had a strong effect on residence time in the lake; floating particles flush from the lake in 1.7 years—nearly 5 times faster than neutrally buoyant particles (8.1 years; **Figure 10B**). In fact, the modeled flushing time for neutrally buoyant particles in Lake Erie substantially exceeds hydraulic residence time estimates (2.7 years; Bolsenga and Herdendorf, 1993). However, the residence time is not uniform across the lake. Average residence times of neutrally buoyant particles released at different sources show a west-east gradient (**Figure 10A**), with the shortest residence times for the particles released at the Buffalo River (less than a month) and longest for those released at the Ottawa and Huron Rivers in the western basin (over 30 months, **Figure 10A**).

Most surveys of environmental plastic pollution tend to collect samples at the water surface, capturing floating plastic only. According to this model, most of the floating plastics sampled in the western and central basin would have been in Lake Erie for <2 years. However, while most virgin plastic used in consumer products—especially one-time use plastic (PlasticsEurope: Association of Plastics Manufacturers, 2015)—is predicted to be positively buoyant, plastic litter is readily found in sediment (Corcoran et al., 2015; Van Cauwenberghe et al., 2015; Ballent et al., 2016). This can be attributed to denser polymer types sinking, but there are other dynamic changes in the buoyant density that plastics are likely to undergo once in the environment, e.g., oxidation or biofouling. These changes are poorly described, but our results indicate the need to resolve these phenomena to effectively model the loads and fluxes of environmental plastic pollution in freshwater and marine systems alike.

CONCLUSION

This study has improved our understanding of the distribution, transport, and fate of plastics in four lakes of the Great Lakes system. As the largest freshwater system on the planet, these critical lakes hold 20% of the world's fresh water. Plastic pollution was documented down to the smallest size class yet reported, shedding light on the magnitude of plastics in a small size class (106–333 μm) that is missing from most existing reports (Hidalgo Ruz et al., 2012; Law, 2016). This led to load estimates of nearly 2 million particles km^{-2}, the highest reported levels in the Great Lakes and possibly any surface water ecosystem. These high numbers can be attributed to the high nearshore population density, a feature unique to inland waterways that does not similarly influence remote ocean basins, and the long hydraulic residence time of some of the Great Lakes (3–100s of years, depending on the lake). Given this time and the recalcitrance of plastic to degradation, fragments of some of the first plastic ever produced for the consumer market are certainly present in the Great Lakes still today. This scenario is likely representative of lakes worldwide, which account for 87% of the planet's freshwater and have an average residence time of 50–100 years[4]—indeed spanning the introduction of plastics to the consumer market.

Data describing the abundance of plastic pollution in the Great Lakes are sparse and will continue to be. Field-based quantification surveys are time-consuming, expensive, and low-throughput. As a result, there is insufficient spatial and temporal resolution of plastic debris in the Great Lakes and other aquatic ecosystems. In addition, detailed data on plastic loads (e.g., from rivers and WWTPs) are needed to determine the plastic budget and to inform future models. Integrating the modeling approach developed here will guide targeted research surveys, experiments, and technological innovation for improved understanding of the ecosystem and public health risks plastic pollution pose to freshwater systems. These are the steps needed to develop a global plastic mass balance transport model to effectively inform the policy, mitigation, and prevention initiatives needed to protect our vital freshwater resources.

Research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

MD, DB, and KW: conceived the study. MD, RC, and BL: performed field sampling, sample processing, and plastic count data collection and analyzed data. DB and RB: developed and ran the transport model and analyzed data. MD, RC, DB, and KW: wrote the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fenvs.2017.00045/full#supplementary-material

[4]https://scied.ucar.edu/longcontent/water-cycle

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Senator SULLIVAN. Thank you for that testimony.

We are now joined by a very distinguished witness, Senator Whitehouse, who has been a leader on this issue, and I am very, very pleased that he has joined us today to testify on an issue that he has not only led on in the Senate, but is very passionate about.

Senator Whitehouse.

STATEMENT OF HON. SHELDON WHITEHOUSE, U.S. SENATOR FROM RHODE ISLAND

Senator WHITEHOUSE. Intermittently distinguished, Chairman Sullivan, intermittently. But thank you to you and Senator Peters. I really appreciate this opportunity.

Senator SULLIVAN. Just so you know, we've probably had about eight or nine senators at this hearing already, so there's a lot of interest.

Senator WHITEHOUSE. Well, there should be, because this is a very important issue. One of the things that we are learning, as you know, is that billions of tons of plastic is going into the oceans.

We did a hearing together in the Environment and Public Works Committee, in which the testimony was that a great deal of that was going into the Pacific, and your Aleutian Islands reach up like an arm across the top of the Pacific and catch an enormous amount of that waste along your shores. I believe that the comparison was that in Rhode Island, we do annual beach cleanup with garbage bags and you have to do it with front-end loaders and containers at a whole level of scale with tons per linear mile of ocean front in some places.

So it's really serious, and what we have learned through the good work of Ocean Conservancy and a scientist, I believe, at the University of Georgia named Jenna Jamison, is that the biggest contributor to that problem is a handful of Asian nations that have horrible upland waste management, and because plastic lasts so long, if you have terrible upland waste management, sooner or later, things work their way to the sea, and then off you go to the races, and then you end up with these billions and billions.

So one of the things that we're recommending in the legislation that you have led on is that our trade representatives start to pay attention to this fact. If it's hitting home in Alaska, if it's hitting home around the world, we should not be paying zero attention, which is the record so far, to this problem of treating a trading partner of ours as if it's totally okay to have zero upland waste disposal, give them competitive advantage because they don't have to pay for waste disposal, and we pick up half of their tab through the trash that we then have to clean up.

The second piece of this that I'll mention in my remarks today is that the stuff goes out there, and we are headed for a world in which there's actually more plastic waste mass in the ocean than there is living fish mass in the ocean. That's not a great place.

But the plastic doesn't biodegrade in the ocean. It breaks down into smaller and smaller and smaller and smaller pieces to the point where those little pieces can be taken up by little phytoplankton, and little creatures in the food chain, whatever is eating down there, gets these little things in them, and then they start working their way back up the food chain. And we have no idea what effect that has on human consumption of fish and on people who have fish, like many Alaskans do, as a big part of their diet. So we need to study that.

And we need to put to work our national labs and our universities to try to figure out how to make a plastic that when you leave it in the ocean, it actually biodegrades back to core elements and reintegrates into the natural world instead of just making smaller and smaller and smaller plastic pieces.

This is a great issue for us to work together on in a bipartisan fashion. It was your leadership that caused the hearing to be held in the Environment and Public Works Committee. It's your leadership that has caused this hearing to be held today. I stand with you, ready to help in any way.

I hope that if we can get through our current standoff on healthcare and go back to more regular order, that our bill becomes something that can move rapidly through the hotline. There's an equivalent bill in the House, so there's a real opportunity here for bipartisan progress. But it would not be possible without your leadership, and Senator Peters is also an original co-sponsor as well as a co-leader of our Oceans Caucus, which has been very successful in moving this forward.

So with all of that, let me express my appreciation to you both. Let me express my appreciation to the Committee for allowing me to come and testify and show my support and ring out with the message that this is important. This is something that our children and grandchildren will be looking at us to say, "Why did you or didn't you do something about this?" And this is a real bipartisan opportunity.

Senator SULLIVAN. Well, thank you very much, and I think you're being a little humble here, because I appreciate the comments about the leadership. But just for the record, the driving force on this, where I've learned a lot about this issue, not just from my constituents, but from Senator Whitehouse. So it is true bipartisan effort and consideration with Senator Peters. Senator Booker, who was here earlier, gave a very impassioned testimony and plea. So I think this is something——

Senator WHITEHOUSE. And, of course, your senior senator, Senator Murkowski, was the original co-founder of the Oceans Caucus and has been a part of this all along as well. So a big Alaska footprint on this, but primarily yours, and I appreciate it. The gavels matter, and you've used yours to great effect.

Senator SULLIVAN. Well, and one thing that we mentioned earlier—this has passed out of committee, in the Commerce Committee, already, bipartisan, and I believe we are beginning the hotline process, and so, hopefully, we can move that soon. But thank you again for your testimony.

Senator WHITEHOUSE. Thank you for the invitation.

Senator SULLIVAN. Professor Duhaime, we have a couple of follow-up questions. Thank you for your patience. Let me just go to kind of two issues that Senator Whitehouse talked about that has really been a theme here. But you're really kind of very well positioned, given your background and your research, to help us understand these issues better.

The bottom line is we really don't know what the impact and health effects are right now with regard to the micro plastics to the health of fish or even the impact for humans, correct?

Dr. DUHAIME. That is true. One of the notes that I wrote down earlier that I heard repeatedly was the quote, "we don't know."

Senator SULLIVAN. Yes. Well, again, we appreciate your professional work and your research and want to encourage you to do that so we do know. But let me get to another question that he raised that I think is also—we can view as an opportunity and a challenge.

I mentioned—and I just submitted for the record—the statement by the American Chemical Council. Senator Peters and I were talking about this before the hearing. Are we getting close, in your view, from the perspective of research and what's going on in industry or academia, with regard to having at least, for example, salt water, a true biodegradable plastic? It would seem to me that would be very, very good for the environment and our oceans, and it would also be an opportunity for entrepreneurs who could ever figure out a way to do that to benefit as well, a win-win.

But do you believe that we're getting there? Because that could be very helpful. We're not there yet.

Dr. DUHAIME. Unfortunately, I do have to admit I'm not a chemist and an expert in the realm of material sciences. So I think you'd be better suited to direct that question at someone with that expertise.

Senator SULLIVAN. OK, because I do think we're seeing that in terms of even Styrofoam and other areas that we could have the potential for a full biodegradable product that could help, and, again, that's another area that we're going to be focused on.

Let me ask you a final question. You know, there has been talk about the Great Lakes. There has been talk about the oceans. Does marine debris that reaches freshwater pose a different threat, different challenge, different way that we should think about it from a policy perspective, than marine debris found in our oceans? Or is it pretty much broadly viewed as the same direct challenge?

Dr. DUHAIME. I think there are a few differences in how the plastic behaves in the environment influenced by the freshwater, which will influence its distribution in the water column. But I think more from a policy and human impact perspective, one thing that we do need to think about differently is that freshwater is drinking water sources, so having a closer look at the impact on freshwater as a drinking water source and serving as a mechanism to deliver plastics to our bodies.

Senator SULLIVAN. Are there any immediate steps our state or Federal agencies could take, in addition to what's in this bill, which is focused in a lot of ways on the oceans, to combat marine debris in the Great Lakes region?

Dr. DUHAIME. I think a lot of the efforts and initiatives are quite transferable to the Great Lakes.

Senator SULLIVAN. OK. Great.

Dr. DUHAIME. So I don't know any other specific recommendations that would be targeted at the Great Lakes.

Senator SULLIVAN. Great.

Senator Peters.

Senator PETERS. Thank you, Mr. Chairman.

And thank you, Dr. Duhaime, for being here and thank you for all the work that you're doing on the Great Lakes. We spent a lot of time during this hearing discussing the oceans, which are vitally important to the planet's health, but as the Senator from Michigan, I'm very concerned about the health of our state as well as the other states around the Great Lakes basin.

You mentioned in response to a question from Chairman Sullivan regarding human health issues, or differences perhaps in freshwater versus oceans, and you brought up the issue of drinking water. I think it's very important, and one thing that I remind my colleagues about frequently here is that the Great Lakes provide drinking water to over 40 million Americans—a pretty significant source of water.

When I hear about your study—and I'd like you to elaborate on your study of the amount of plastic that you're finding in the Great Lakes, particularly microfibers. This is obviously being ingested by human beings, 40 million who are drinking out of the Great Lakes. To what extent do treatment plants deal with this pollution when we're drinking that water? Are we effective in doing that? Is that a major concern that we have to consider?

Dr. DUHAIME. I personally don't have experience monitoring or evaluating drinking water treatment. I have been into multiple waste water treatment plants to monitor the processing through those types of treatment plants, and then what is output to the natural system. But I think one thing that does need to be done is looking at the source of drinking water and seeing what does pass through and how treatment systems are treating it.

Senator PETERS. So at least from your background, there has not been a lot of research into that area at this point?

Dr. DUHAIME. Not of drinking water.

Senator PETERS. So this is—we know that microfibers and other types of plastics are very extensive in the Great Lakes. In fact, if I recall from the testimony you just gave, you saw some of the highest levels ever. Would you elaborate on that, please?

Dr. DUHAIME. Yes, that is true. I also believe that is a difference that you will see emerging when we start comparing counts and concentrations from marine systems to the Great Lakes. As you mentioned in your opening remarks, there is something to the dilution effect, and when you consider the concentration of humans living around coastlines, for instance, the Great Lakes, and the amount of water that's there, it is much more concentrated, and so that gives rise to the opportunity for greater incidence of encounter with humans with organisms living in the water.

Senator PETERS. What was the figure you gave for the Detroit River?

Dr. DUHAIME. That was 2 million particles per square kilometer—was the value there that we counted.

Senator PETERS. And how did you compare that to the normal? You said that was the highest concentration that you've——

Dr. DUHAIME. Yes. So prior in the Great Lakes, it was—half a million was the greatest value before our study was performed, and that was in the Eastern Basin of Lake Erie, so generally less close to the coast, and I think that could have been influencing our high concentrations in the Detroit River.

Senator PETERS. So that's why you think there's a difference in the findings from previous findings of researchers in the Great Lakes?

Dr. DUHAIME. Yes. I think one of the reasons why our study was enlightening was the greater number of studies. So for more statistically robust counts, you need more sample points and greater samples. That actually gets you another bottleneck in this type of research, and the quality of the data, the reliability of the data that comes out of it is that—I think one of the problems right now is the—the best I can refer to it is that we're using cave man approaches to plastic quantification, that we really need improved analytical approaches to bring the data collection where it should be in the 21st century, so really harnessing the applied chemistry and physics that we know is out there.

Right now, what we do is we go out, we pick up plastic, and we count it, and that's usually with a plastic nylon mesh net which—you mentioned previously that fibers are an emerging issue, which is very much the case, and we see them enmeshed in the tissues of organisms in the Great Lakes or in that digestive tract. But how can we reliably count fibers with a nylon mesh net?

So there are certainly advancements in our ability to collect that raw data, those count data, that could be improved. But why are we simply picking things up and counting them with our eyes? It's because these are the only techniques that are available to us. They're inexpensive. But we can and should, with funds provided, improve the analytical capacity to collect data.

Senator PETERS. In the response to the question from Chairman Sullivan about the differences between freshwater in the Great Lakes and the oceans, you mentioned, of course, drinking water, which you elaborated on with my question. But you also mentioned that the distributions are different. Would you please elaborate on that?

Dr. DUHAIME. Distributions of different plastics?

Senator PETERS. Correct, that it's different in the Great Lakes, and the movement is different than what you may find in the oceans, and why that should be a concern to us?

Dr. DUHAIME. Yes. So those differences stem from really the physical properties of water and salt versus freshwater. So the lower salinity means that the plastic that would normally float on the surface of the ocean will find a different place to settle or find its neutral position in the water column. So things that float in the oceans could presumably sink in freshwater, and our models have confirmed that floating plastic leaves the lakes faster than non-floating plastic. So that in a closed or more relatively closed system like the Great Lakes could lead to a higher concentration, a higher residence time of plastics in the lakes.

Senator PETERS. Well, given your extensive study—just one final question, Mr. Chairman—what do you believe are the next research steps that we need to take to improve our understanding of the Great Lakes and the debris problem that's there?

Dr. DUHAIME. So as has come up several times in the second panel, the studies of organismal impacts of ingestion and inhalation, including humans, is of utmost priority. Also, updating the standards for measuring risks are, I think, an important element that deserves some discussion, that are more appropriate for the properties of plastic. So in our kind of regiment, there are mechanisms to evaluate risk, environmental risk, put forth by agencies such as the EPA. Currently, they're not well suited to describe and define the risk incurred due to plastic.

As I mentioned, improved analytical techniques are essential to bring our data collection to where it should be, as well as improved modeling of plastic transport. So in the absence of high throughput, highly accurate data collection, an alternative mechanism to give us information about where plastic is going, which habitats are most at risk, could be employing hydrodynamic models to predict where it will go and how quickly, as well as—this is outside of my expertise—but economic and health and societal impacts, and more the study of the societal impact of plastic pollution, its cleanup, and its prevention, I think, are needed to help define incentives for change.

Senator PETERS. Thank you, Doctor. I appreciate your testimony today. Thank you.

Senator SULLIVAN. Professor Duhaime, thank you again for your testimony, and we very much appreciate the work you're doing. We want to encourage you to keep it up and continue to help us have a better understanding. But you did a very good job of that today.

So without any further questions, this hearing is now adjourned.

[Whereupon, at 11:41 a.m., the hearing was adjourned.]

A P P E N D I X

PREPARED STATEMENT OF THE U.S. COAST GUARD

Introduction

Marine debris is a risk not only to the coastal and offshore environment, but also poses a hazard to navigation As the lead Federal regulator for the maritime industry, the Coast Guard actively partners with the National Oceanic and Atmospheric Administration (NOAA), the Army Corps of Engineers (USACE), the U.S. Fish and Wildlife Service (USFWS), and other members of the Interagency Marine Debris Coordinating Council (IMDCC) to ensure safe navigation and protect the marine environment.

Interagency Coordination for Marine Debris

NOAA is the lead agency for conducting research, monitoring, prevention, and reduction activities for marine debris. NOAA's Marine Debris Program leads this effort and NOAA chairs the Interagency Marine Debris Coordinating Committee (IMDCC). The Coast Guard supports NOAA by participating as a member of the IMDCC.

The Marine Debris Research, Prevention and Reduction Act of 2006 identifies the Coast Guard as an agency that NOAA should coordinate with to address marine debris issues. To date, the Coast Guard has been fully engaged with NOAA in support of marine debris monitoring and tracking in order to ensure safe navigation for shipping and to protect the marine environment. Coast Guard actions in support of NOAA depend on the type of the debris.

The Coast Guard, as the Federal On Scene Coordinator (FOSC) for the Coastal Zone, leads removal actions under the National Contingency Plan (NCP) for any debris that poses a potential oil or hazardous substance threat to the environment. Additionally, the Coast Guard coordinates with USACE to ensure our waterways are free of any hazards to navigation. Upon report of an obstruction to navigation in U.S. navigable waters, the Coast Guard and USACE work together to develop a removal or mitigation strategy. If the hazard to navigation is within a federally maintained shipping channel, the USACE will typically take action to remove it. If the hazard to navigation is not within a federally maintained channel, the Coast Guard may, among other things, choose to mark the hazard with a buoy and broadcast warnings to mariners.

Critical to the Coast Guard's decision making process is the exact nature of the risk posed by the object to safe navigation. USACE and Coast Guard decision-makers ensure close coordination with state and local authorities and, in some cases, those non-federal authorities may choose to remove the object. Coast Guard resources and personnel may also be requested by NOAA to help with identifying, tracking, and monitoring debris by conducting overflights, with NOAA representatives aboard. In addition, Coast Guard resources and personnel partner with NOAA to help with documentation of, and response to, marine animals entangled in marine debris (*e.g.,* marine mammals and sea turtles).

The Coast Guard and NOAA actively work and plan together at all levels of both agencies. At the national level, the Coast Guard participates in interagency conference calls, hosted by NOAA, to provide strategic interagency coordination, awareness, and information sharing. At the regional and local level, operational commanders at the Areas and Districts are actively engaged with other federal, state, local, and tribal partners. Further, the Coast Guard coordinates outreach and education on marine debris prevention through its Sea Partners program and the Coast Guard Auxiliary and has partnered with NOAA through the IMDCC on outreach efforts on the prevention of waste (*e.g.,* garbage and plastics) generated by recreational vessels.

Pollution Prevention Operations

While debris removal is an important part of safeguarding the environment and the MTS, the Coast Guard plays an important role in preventing marine debris from entering our waterways and oceans. The Coast Guard leads this effort through examinations of foreign vessels for compliance with the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex V. Coast Guard marine inspectors also verify that domestic vessels comply with the Act to Prevent Pollution from Ship (APPS), and the regulations associated with that U.S. law. The Coast Guard also plays a critical role in verifying that port facilities meet their legal requirements in accepting garbage and refuse from vessels calling on U.S. ports. This is a critical component in combating marine debris. Vessels must be able to offload their garbage when in port, so that they will not be tempted to dispose of it at sea.

Conclusion

The Coast Guard will continue to work closely with NOAA and through the IMDCC to address the potential impacts of marine debris and will respond to substantial pollution threats or hazards to navigation.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. GARY PETERS TO MELISSA B. DUHAIME, PH.D.

Solutions for Debris

Question 1. Dr. Duhaime, you described in your written testimony a host of impacts to the environment and human health and safety. We know plastic is a big part of the problem along with abandon and derelict fishing gear and vessels and other items.

What are some potential solutions for debris in the Great Lakes and might there be different solutions in the oceans?

Answer. The solution to the plastic debris crisis in the Great Lakes and in the oceans is universal; all components of the plastic pollution equation must be addressed.

Plastic pollution is a function of the plastic produced (which itself is a function of the plastic demand and supply of raw materials—feedstock) in combination with the extent of plastic waste management. There are four major dependent or interacting elements: plastic production, demand, feedstock supply, and waste management. Solutions in the Great Lakes and oceans alike must address all four.

First, we must address production. For a realized reduction of plastic produce, one must first ask "which sector can we reduce, so as not to decimate the plastic industry nor eliminate the production of plastics beneficial to society?" It is the production and use of disposable one-time-use plastics that must be curbed, especially for food packaging (one of the strongest plastic markets), rather than continue to rise. This argument is focused there. There is a systemic cultural addiction to the convenience of one-time-use plastic, yet plastic pollution is putting our ecosystem at risk.[1] The full consequences of this risk are currently unknown, but the outcome has the potential to be dire for humans and the environment, alike. We know plastic is found in the food we eat,[2,3] but less discussed is that it also exists in the air we breathe.[4] And not without risk: a decades old study confirmed that 97 percent of the malignant lung tumor specimens examined contained cellulosic and plastic fibers.[5] Shifts in production to secondary, recycled products or more biodegradable plastics are considered below.

Next, we consider demand and feedstock supply. There is money in plastics. We can't expect the demand for plastics to decrease on its own, especially if crude oil and natural gas-derived feedstock is not limiting. Nor with the good will of a handful of eco-minded first-world consumers decrease global demand. It may require policy to incentivize reduced production of one-time use disposable plastics or to shift the supply of primary plastic feedstock, be they derived from crude oil refining, natural gas processing, or biological material. Interestingly, the U.S. Energy Information Administration is unable to determine the specific amounts of each feedstock that go into plastic production, so the feasibility of a detailed evaluation of these markets is limited. Though I can highlight possible avenues to explore, the economics of the above suggestions are beyond my scope of expertise, yet their consideration is motivated by the ecosystem and human health risks of plastic pollution, to which I have spoken.

Finally, in considering waste management, I address two major areas where the search for solutions can be focused: effectiveness of recycling initiatives and the development of biodegradable plastic (in the next section). Recycling in its current form is an insufficient solution to prevent plastic pollution.

First, in discussions of waste management across the state of Michigan, other Great Lakes states, and Canada, it has become clear that recycling programs in the U.S. that are managed on a local scale simply do not work. For instance, even in the progressive Midwestern City of Ann Arbor, where most residents value and intend to recycle, the market for recycled materials is so volatile that it has been prohibitively risky to invest in management of recyclables. Economic buffers are needed to support the efforts of (especially small) municipalities to create and maintain recycling programs in the face of market volatility.

Second, incentives for manufacturers to use recycled materials are needed, as well as for *which* secondary items are produced from recycled plastic. These items must have a large potential for *displacement*—the successful market competition with primary, non-recycled plastics.[6] For, it is not the amount of material collected for recycling that matters for reducing environmental impact, but the amount of primary plastic that is displaced on the market.[7] These items must be of great and sustained technical and economic value for maximal displacement,[6] thereby avoiding *downcycling,* where the product's value decreases after being broken down into its constituent parts due to poor quality recycled material. Representing the current standard for reporting practices and foci, the Plastics Division of the American Chemistry Council represents and reports on activities of the leading manufacturers of plastic resins. This group often presents data lauding the increase in plastic recycling in recent years. However, these data do not account for the exponential increase in plastic production with time (if they did, recycling rates may flat line, or even decrease with time) and they tend to focus on the *amount* of material collected. In the future, maximally useful and productive assessments of the robustness and impacts of recycling systems must include the rate of primary plastic displacement and the market value of recycled items as they cycle through the economy. These are the reports policy makers should seek when considering effectiveness and robustness of recycling systems.

Third, data shows that the majority of consumers are confused by plastic recycling programs.[8] This also reduces the chance for success of introducing easy-to-degrade/ocean-degradable (as mentioned in the oral testimony) plastics. With more diverse plastic landscape, including knowledge of environmentally "safe" plastics on the market, consumers may be granted unintentionally the license to mismanage all plastic.

Innovations to Reduce Debris

Question 2. Innovation, technology, and discoveries have helped to mitigate environmental problems in the past. Advancements have created some biodegradable plastics, but we understand that there are issues with biodegradable plastics actually degrading, especially in marine environments.

Can you clarify what potential might exist to create biodegradable materials or more easily recycled materials to help mitigate this problem?

Answer. Current chemistries of biodegradable plastics are intended to degrade in compost environments: warm habitats with minimal oxygen that are laden with microorganisms that specialize in the breakdown of complex carbon—such as the material found in soil, but which also includes plastic.

Until we are able to reduce and eliminate the demand for one-time use plastics, one effective shift could be from petroleum-based plastics to biologically produced plastics ("bio-plastics"). For instance, PHA plastics (polyhydroxy-alkanoates) and other "compostable" plastic can be produced from plant material, such as corn, potato, and soybeans (though note, compostable plastic can also be produced from petroleum-based resins). The biodegradation of bio-plastics is more rapid than petroleum-based plastic, especially when conditions are optimal. Optimal conditions include fully contained compost or a healthy, functional landfill operation with abundant airflow.

However, when not optimal (especially when oxygen becomes limiting), the degradation products of these bio-plastics (and even the "compostable" petroleum-based plastics) can be detrimental to the planet, potentially more so than the accumulation of persistent petro-plastics.

If easy to degrade and compostable bio- and petro-plastics inundate our landfills (as they will under current waste management practices), the rate of methane production by landfills will increase. In the US, landfills are already the third largest source of methane, a greenhouse gas 25 times more detrimental to our atmosphere than carbon dioxide. Though, when managed properly, there are many innovative possibilities for such easy-to-degrade and compostable plastics. For instance, if completely harnessed in a plastic-specific bioreactor, methane can be used as an energy source rather than being released to the atmosphere and continuing to contribute to current global warming. Further, informed by the knowledge delivered by environmental bioprospecting (more in next section), these plastic-specific bioreactors can be intentionally seeded with microorganisms able to degrade such plastic. This concept is similar to how wastewater treatment plants are engineered with organisms to scavenge phosphorus to prevent environmental phosphorus pollution. Such investments in waste management infrastructure innovation are requisite. The time is ripe for their development and installation, as most waste management infrastructure in the U.S. is aging and in need of replacement.

In summary, there is potential for innovative design of new plastics, for instance compostable (already on the market) and other easy to degrade (*e.g.,* in ocean or freshwater environments) resins. However, the shift towards easy to degrade/compostable resins for one-time use plastics *must* be met with a transition to innovative waste management infrastructure (*e.g.,* bioreactors, plastic-specific or not). Otherwise, the risk to planetary health due to enhanced atmospheric methane could be incurred.

Research in Action

Question 3. Dr. Duhaime, in your written testimony, you describe your data and research contributing to action plans, educating the public, and recommendations for addressing the problem of debris in the Great Lakes.

Can you elaborate on the ways in which your research is contributing to developing solutions to this important environmental issue?

Answer. As a lab focused on environmental microbiology, our current work is focused on the microscopic life forms that live on plastic debris (in both the Great Lakes and ocean systems). As little is known about these organisms, our first task is always to identify which microbes are there and how they differ from the native water communities. For instance, from these data types (essentially, species lists) we have been able to identify the core species that are typically found on plastic in the oceans and lakes. These plastic-dwelling microbes are candidates to explore for the potential to degrade the polymers. The next level of investigation (beyond the "species list") requires the reconstruction of the genomes and metabolic pathways of these microbes, an analysis currently active in our lab. These data will indicate whether plastic-dwelling microbes encode metabolic pathways with the potential for polymer degradation. In this way, we are bioprospecting new microbes and metabolisms that may be able to breakdown plastic.

Notably, these approaches have also identified potential pathogens living on plastic. Our current data will confirm whether these pathogenic strains indeed exist on plastic and carry the genes needed for pathogenicity.

We have been working in partnership with the NOAA Marine Debris Program for 4 years. This group continues to serve as a critical and effective platform for researchers to disseminate their findings to outreach, education, and clean-up organizations, as well as to hear from these groups to learn the on-the-ground research questions and needs. This system works. Its funding is critical.

As far as recommendations, we need greater industry partnership with the basic research of academia. For instance, with our expertise in prospecting and harnessing microbial diversity and metabolisms, we could work with plastics producers to more specifically define the microbial drivers and by-products of biodegradation to design next generation plastics with safe breakdown products. Such industry-academic unions are where the real potential for innovative change is possible.

Research for Solutions

Question 4. Dr. Duhaime, in your written testimony, you shared with us some of the modeling work that you and your collaborators have done to show how debris and its movement in the Great Lakes can change over time.

Are there ways that we can use the information that you have learned through your research to improve the effectiveness of our debris prevention and debris clean-up efforts?

Answer. Note this response mentions the Great Lakes, but can be applied to ocean systems as well.

Our research, and that of other researchers in the Great Lakes, has quantified the abundance of plastic across the Great Lakes and its tributaries [9-12] and modeled (in other words, combined math and physics to predict) the distribution and movement of plastic through the lake.[12,13] This knowledge can be applied to minimize the ecosystem risks incurred by increasing the effectiveness or debris prevention and clean-up efforts. By helping to identify patterns in the distribution and movement of plastic, we can better (1) identify sources of plastic, (2) determine whether some biomes are more at risk than others, *e.g.,* breeding grounds or larval nurseries of economically important fish populations or endangered and threatened species, and (3) strategically focus clean-up efforts on habitats that are most impacted.

Differences with prior research

Question 5. Dr. Duhaime, the extensive work you did in 2014 has found plastic concentrations much higher than previous studies and found that most of the plastics in the Great Lakes are broken down, or "secondary," plastic fragments.

What might have contributed to the different findings between your work and earlier work? Did the extensiveness of your sampling contribute to the observed differences? Is the nature of debris in the Great Lakes changing over time?

Answer. Previous surveys of plastic pollution in the Great Lakes were performed only 1–4 years prior to ours.[10,11] We do not expect these differences to have arisen due to a change in plastic over such a small window of time.

We attribute the differences to be due primarily to two differences between the studies. The first difference is that we collected and counted plastic down to 100 µm, while the smaller size examined in previous reports was three times larger.[10,11] All plastic in the environment will fragment into smaller and smaller pieces, thus one would predict the smallest size classes to have the most plastic. We found this to be the case in the Great Lakes.

The second reason we found such higher counts was due to where we sampled. In addition to sampling the middle of Lake Erie's western, central and eastern basins, we strategically sampled the coastline around high population density urban centers (Lake St. Clair, Detroit River, Cleveland, Erie, Buffalo). These sites were found to contain the highest numbers of plastic. The previous study in Lake Erie restricted their sampling to the middle of the lake.[10]

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